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ELEMENTS

OF

NATURAL PHILOSOPHY,

WITH SOME OF THEIR

RESULTS AND APPLICATIONS.

DESIGNED FOR

SCHOOLS, ACADEMIES, AND PRIVATE STUDENTS.

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PREFACE.

To make an elementary class book on natural philosophy, adapted to the wants and tastes of the generality of youths, from 15 to 20 years of age, such as we find in our better schools and academies, is a task of no common magnitude; and the fact that it has never been accomplished, is a sufficient demonstration of the difficulty.

It is not for us to say how well we have succeeded, or how near we have approximated even to our own *beau ideal* of the work demanded; and of course our efforts have been to mould this work according to our ideal standard, and if that standard is wrong, or a mistaken one, then we have failed altogether.

If, on the other hand, our views are correct—if we really understand the wants and wishes of both teachers and pupils, we are in a great measure qualified to meet them; and to convince the reader that we do understand this, we say that a work of this kind should have all the essence of science in a small compass, in a style of language not elaborate, nor yet too brief—not rigidly demonstrative, nor wholly void of demonstration—not minutely mathematical, and at the same time making free use of the mathematics. It should not be a work for a philosopher already made, nor one for a child, nor for a thoughtless person who is incapable of becoming a philosopher. It is our opinion that with mathematical problems, and logical propositions, may be united a popular and spirited style, describing the common application of philosophical principles, not excluding even anecdotes and pleasantry, when it does not compromise dignity. As far as we can judge, there are two classes of scientific and philosophical authors. One who aims to be minutely theoretical and mathematically exact, and who desires to appear so in the eyes of the most rigid critic. The works of all such must be dry and uninteresting; valuable indeed for works of reference, but they are unfit for class books, for they cannot meet with sympathy among the general mass of pupils. The other class reject theory, omit the examination of principles, compile mathematical rules, and call them mathematics; cull out philosophical *facts*, and call them philosophy: in short, they seemingly make an effort to adapt their works to the minds of the most unthinking, and to the meanest capacity; and it is unnecessary to say that such works must be wanting in spirit and life, and incapable of inspiring interest in the subject on which they profess to treat.

We have designed to make this book neither a dry and formal scientific class book, nor a mere compilation of philosophical facts: but we have attempted to work up theory and fact together; to unite demonstration and observation, and the practical results of all. Our sole object has been to teach, to interest the pupil, and allure him on in his efforts to learn; and to

accomplish this end, no invariable rule could be followed, and no hair splitting logic has been attempted. Our efforts have been to bring the different subjects right home to the mind of the pupil, not merely in such a light that he *may see*, but in such a light that he *must see*, the chain of cause and effect, and the *rationale* of every result, provided he really gives his attention.

We have put more philosophy into this volume than can be found in the same space in any other book. By philosophy we mean the rationale of the thing, in connection with the fact. Every fact concerning falling bodies might be minutely and properly stated *and not have a word of philosophy about it;* but when the fundamental facts are singled out to be determined by observation, and then a course of reasoning applied which closely unites fact to fact, such a course of reasoning is philosophy; and in this sense we claim to be more fully and clearly philosophical than any similar class book now before the public. In confirmation of this, we call the reader's attention to our exposition of the subject of gravity, falling bodies, the steel-yards, specific gravity, hydrostatics, the steam engine, and last, though not least, the magnetic telegraph.

Some mathematical investigations, which are supposed to be of too scientific a character to be appreciated by all the members of a class, are put in text notes, and so arranged that they may be omitted in regular lessons; but these are the most valuable parts of the work, to those who are prepared to read them.

We have been very particular to call attention to the practical application of every principle that has come under investigation; and to be more acceptable on these points, we have sought that kind of information from practical men, both in the work-shop and in the field, and this gives to theoretical knowledge its vigor and its spirit.

In relation to the magnetic telegraph, we claim to have surpassed all other works that we have seen. We have given the whole of the subject, —keys, relay magnets, station batteries and all,—omitting only the clock work that rolls off the paper, as that has nothing to do with the principle, and would serve only to confuse the mind. On this subject we acknowledge essential aid from Mr. Moses Johnson, a practical telegrapher, engaged in the office at Cincinnati, and from a work of this gentleman we have taken several extracts by his permission.

We do not approve of questions at the bottom of the page, for then the pupil *who reads but to recite*, will pay so much attention to the questions as to lose the spirit of the work. If a teacher requires questions for the purpose of examining a class, it is an indication that he should be one of the class, and not its teacher; but nevertheless, as questions may help the real student to analyze the matter, and help the teacher in times of haste, we subjoin a few at the end of the work.

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NATURAL PHILOSOPHY.

SECTION I.

Chapter I.—Definitions and Preliminary Principles.

The term "Philosophy," in its original sense, was "love of wisdom," but in its modern signification it is an exposition and examination into the reason and nature of things; and in this general sense it will cover almost every subject.

When we examine and explain the truths in connection with mind, we call it *Mental Philosophy.*

When we examine and explain our duties and relations to each other and to God, we call it *Moral Philosophy;* and when we examine into the facts and truths of the material or natural world, we then call it *Natural Philosophy.*

We can have no conception of the material world, independent or aside from *matter*, and we can have no conception of matter independent of length, breadth, and thickness.

A separate collection of matter, of whatever kind, may be called a *body*, and the smallest possible division of any body, may be called a *particle*. The terms *body* and *particle*, are of very frequent use in a work on Natural Philosophy.

We cannot conceive of two bodies occupying exactly the same space in the same time, nor can we conceive of a body without length, breadth, and thickness, hence we have two properties essential to the very existence of matter, namely, *Impenetrability* and *Extension*. Besides these two essential properties, there are two others always in connection, namely, *Inertia* and *Attraction*.

All bodies are more or less divisible, therefore, *divisibility* is a common, if not an essential property of bodies.

Besides the five common properties already mentioned, there are others which do not all belong to every body, but some of them to one body and some to another; hence these are called the *peculiar* properties of bodies. These are *Density*, *Rarity*, *Hardness*, *Brittleness*, *Elasticity*, *Malleability*, *Ductility*, and *Tenacity*.

By impenetrability, we mean that one body cannot actually penetrate another and occupy the same space in the same time. Although any substance may be plunged into water, the particles of water are pressed aside and not penetrated by the body; when a nail is driven into wood, the wood is not penetrated by the nail, but the particles are pushed aside to make way for the nail, and the two bodies occupy different spaces at all times. When sugar or salt is dissolved in water, or a metal dissolved in an acid, the particles of the substance dissolved are supposed still to be entire, for the water or acid can be removed and the dissolved substance again obtained in a solid state.

It would be endless to cite every consideration which proves the impenetrability of matter, and we conclude by asserting that we can conceive of no two substances in one absolute space without forming a new substance by their union, or one body annihilating the other.

Extension. Every body must have extension, however small it may be. This truth must be admitted, from the impossibility of conceiving a body to exist without it. Figure is the result of extension, and the endless variety of figures in the material world is made by the various relations which may exist between length, breadth and thickness.

Some solid bodies which are produced by nature, have always the same figure wherever found, as the crystalised salts; but other bodies are so irregular that they cannot be compared to any mathematical figure whatever. Fluids take the form of the vessel in which they are placed.

Divisibility. By divisibility is meant, that any body can be divided into parts, and those parts again divided into smaller parts to limits unappreciable to our senses.

Philosophers differ as to the extent of the divisibility of matter, and the fact is hid in the nature of matter itself, but with such abstrusities we have nothing to do.

We know that some kinds of matter are divisible to an astonishing degree. A single grain of musk will scent a room for years, and lose no appreciable part of its weight, and we can account for this in no other way than by supposing the particles of musk constantly flowing into, and mixing in with the atmosphere of the room, by which they are brought in contact with our senses.

Gold may be hammered so thin as to take 282,000 leaves to make an inch in thickness; a single grain of gold may be spread out so thin as to spread over fifty square inches, and still the particles not separated.

From all we can learn, in both the philosophical and chemical world, matter is neither created nor destroyed, but is continually changing, passing from one form to another, from death to life and from life to death; what seems to be annihilation is only change;—thus, wood apparently consumed by fire, has only its particles changed and dispersed, but they are still in existence, and can again be united in similar bodies.

However, as this speculative subject belongs to chemical philosophy rather than mechanical philosophy, we pass it over.

Inertia. Inertia is passiveness or want of power,—a particle of matter has no innate power of itself to act or to cease acting. It is incapable of putting itself in motion, or resisting motion when motion is once created. But this property is such an essential part of the laws of motion that it will be treated of in full in the next chapter.

Attraction. By attraction, we mean that property in bodies which causes their particles to unite, or causes masses to tend towards each other. We know nothing of the real principles of attraction, and therefore we are not able to determine whether there are different kinds of attraction or not, but it is generally believed, and we think with reason, that there are at least two kinds. One that we call attraction of *gravitation*, the other *electrical* attraction. By observation, we learn that the first pervades all material substances in proportion to what we call weight

of the substance, and has no reference to the nature or quality of the substance. The last has more or less dependence on the nature of the substance, and on some substances, such as glass, amber, wax, fur, and some other bodies, it is excited by friction; certain different bodies either naturally possess it, or create it by coming in contact with other bodies, and the action under such circumstances is called *chemical attraction*. That which causes certain metals to exert unusual attraction, and makes the needle point towards the poles of the earth, is but a modification of *electrical attraction*, which we call magnetism. There is also an action called *capillary attraction*, which causes liquids to rise in tubes and ascend in very narrow crevices. Whether this is a modification of electrical attraction, or a combination of both gravitation and electricity, or a force independent by itself, is not known; many explanations have been attempted, but none of them are satisfactory.

Cohesion. The force which keeps the different particles of the same body together is called attraction of *cohesion*, and this acts only when the particles are in near contact.

We have thus given but little more than definitions of these properties of bodies, but before we leave this subject we will mention some experiments, proving these properties, and in some degree call the attention of the pupils to the utility and harmony of the present order of nature.

Without *cohesion* there could be no masses of matter, no order among material bodies; there could be no works of art, for every thing would crumble to dust, and all would be a chaos.

To experiment on this property and to bring it forcibly to the mind, take two pieces of lead with fresh cut plane surfaces, free from dust and all other foreign matter, put the plane surfaces together and they will *adhere* with considerable *energy*, that is, show *cohesion*, and the more so as the surfaces are larger and more perfectly brought in contact.

Two pieces of plane glass perfectly free from all intervening matter, will present the same phenomena. In short, all smooth solid substances, capable of being brought in actual contact of surfaces show *cohesion*. But this kind of

attraction is much stronger in some bodies than in others, and therefore some suppose it to be but a modification of electrical attraction.

It is stronger in the metals than in most other substances; stronger in solid bodies than in liquids, and weakest of all, if not entirely wanting, among the elastic fluids and gases.

It is the force of *cohesion* that enables iron wire to sustain a heavy weight without separating its particles; for the want of an equal amount of *cohesion*, other kinds of wire of the same size will not sustain an equal weight; a small leaden wire will sustain very little.

Some suppose that it is the weakness of this property in certain bodies that forms liquids. A few particles of water will cohere and form a drop, but it is for the want of greater cohesion that the drops are not larger. The drops of some liquids are much greater than others.

Fluid bodies whose particles easily move among themselves,* when in masses, arrange themselves in globular shapes, by the influence of the mutual attraction of their particles, each outside particle claims as near an approach to the centre of the whole mass as any other particle, and each being equally free to move, the outside surface of the mass at every point must be equally distant from the central point, and this forms a globe. The shape of rain-drops, hail-stones, globules of mercury, are all illustrative of this law; and it is generally admitted that this may account for the globular shape of the sun, moon, and planets. Shot is manufactured on this principle; the melted lead is turned through a sieve at a great height from the ground, and the separated portions arrange themselves into globules, and in that shape cool before they reach the ground, and thus become solid.

Capillary Attraction may be observed by putting a very small glass tube open at both ends into water, the water will rise higher in the inside than on the outside. The end of a sponge or lump of sugar put in water will cause the water to rise up into the whole mass. These substances may be considered as composed of masses of little tubes; the wick of a candle or a lamp is supplied with oil during combustion, on the same principle; water coming

* That is, for the want of sufficient cohesion.

to the bottom of a stack of hay will wet the whole mass and some persons thus account for springs coming out at the top of hills, and good wells on abrupt and elevated situations; they say the pores of the ground act as capillary tubes and water ascends from below, but on this point we hazard no opinion. Without capillary attraction we should have no vegetable world,—by it sap ascends in trees and moisture nourishes vegetables.*

Wood is full of small capillary tubes, and when these tubes contain no water or sap, the wood is said to be dry, and it shrinks into smaller space; when again brought in contact with water, the fluid will gradually re-ascend into all its parts and expand. On this principle, a dry wedge of wood driven into the crevice of a rock and afterwards saturated with water, as when the rain falls upon it, will swell and sometimes split the rock.

Some mill-stone quarries are worked in this manner in Germany.

Electrical and magnetic attraction we shall defer until we treat exclusively on these subjects. Chemical attraction, which is supposed to be essentially electrical attraction, belongs to chemistry, and we pass over it to treat more at large on

ATTRACTION OF GRAVITATION.

The theory of universal gravity which immortalized the name of Newton, was first advanced by that philosopher in the year 1666, and marks the greatest and most important era in science, for it at once opened a channel for profound investigation, especially in the astronomical world. Important and remarkable as this theory is, it is fully expressed in the following words:

Every particle or mass of matter in the universe attracts every other mass, in proportion to the quantity of matter directly, and inversely as the square of the distance.

That bodies would fall to the surface of the earth was of course always known, but the idea that the extent and force of the fall had any connection with the size or mass of matter contained in the earth, was not advanced prior

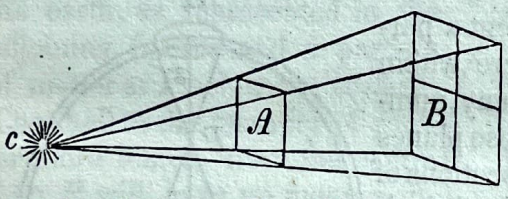
* This has been disputed of late,—the opponents or reformers say, that the circulation of moisture in plants must be ascribed to the principle of life, the same as the circulation of blood in animals, and they may be right.

to Newton's time, and from this idea alone originated the now well-established and beautiful theory of universal gravity. If the hypothesis be true, thought Newton, that matter attracts matter, the entire attraction of the earth must be in a line towards the earth's centre, the same as though every particle of matter composing the earth was collected at that point.

If bodies fall on the surface of the earth by the power of the earth's attraction, and the *concentration* of that force situated at the distance of the semi-diameter of the earth, the next consideration was the law of decrease of the force as we rise above the earth's surface.

Now by a mathematical law easily perceived and readily understood, any influence or force supposed to spread out in all directions from a point, whether it be light or gravity, must diminish in intensity in proportion to the square of the distance.

Fig. 1.



For conceive rays of light or gravity to pass from *c* to the surface *A*. The same number of rays, if suffered to pass to a double distance *B*, will cover over four times the space, and consequently there will be but one-fourth of the light or the influence on the same space.

If the distance be three times the first distance *A*, the surface spread over would be nine times the surface *A*, and of course the influence on the same space would be only one-ninth of the influence on *A*, &c. &c. The influence or intensity diminishing in proportion as the square of the distance increases. Thus, if the distances are 1 2 3 4 5 6

The forces will be 1 $\frac{1}{4}$ $\frac{1}{9}$ $\frac{1}{16}$ $\frac{1}{25}$ $\frac{1}{36}$ &c.

We may at once perceive that this force must exert the greatest influence immediately on the earth's surface, and must decrease both ways, upwards and downwards. For conceive a body placed at the centre of the earth, it is manifest that it would be attracted in all directions alike, for the attracting matter, the body of the earth, would be

all around it, and hence the result of such attraction would be nothing. Place the body a little distance from the centre and there would be more attracting matter on one side of it than on the other, and of course the resulting attraction, though small, would be in a line towards the centre. Remove the body a little further from the centre and the resulting attraction would be greater, and reasoning the same way, we shall find the attraction greatest of all at the surface of the earth, for there all the attracting matter of the earth is on one side of the body attracted. Admitting the general theory of gravity to be true, the force of attraction from the earth's centre to its surface increases as the distance from the centre.*

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* NOTE. This truth is demonstrated to mathematical accuracy by the two following propositions:

Prop. 1. *A body or particle of matter situated anywhere within a spherical shell of uniform thickness and density, would be attracted equally in all directions.*

Suppose P to represent a particle of matter anywhere within a spherical shell. Let any number of straight lines whose planes may cut out opposite sections of the shell, as A and B in the adjoining figure, be drawn from P.

Put x to represent the distance of A from P, and y to represent the distance of B from P, and as A and B are of the *same* thickness, we have, by geometry, the proportion,

$$\text{As } A : B :: x^2 : y^2$$
$$\text{Or } Ay^2 = Bx^2 \qquad (1)$$

Now let f represent the attraction of A on the particle P, and F the attraction of B on the same particle,

Then, by the theory of gravity, we must have

$$\text{As } f : F :: \frac{A}{x^2} : \frac{B}{y^2}$$

By multiplying the last couplet by x^2y^2 we have

$$f : F :: Ay^2 : Bx^2$$

In the application of this principle to terrestrial gravity, the distance from the centre of the earth to its surface

---

But by equation (1) the last two terms of this proportion are equal, therefore the two first must be equal.

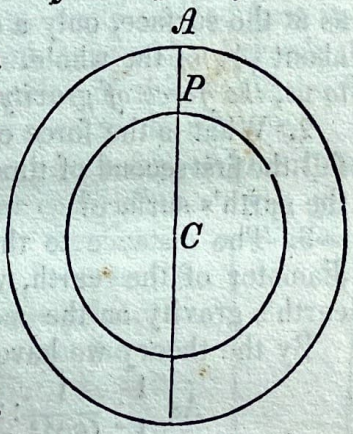
That is $f=F$

As f and F are equal forces in exactly opposite directions, the particle P will not be influenced by them.

But A and B are any sections in *any opposite* directions, therefore the effect of the entire attraction of a shell on a particle anywhere within it must be *zero*.

Prop. 2. If the earth is taken for a homogeneous mass, then

As the force of gravity at the surface of the earth, is to the force of gravity at any point below the surface, so is the radius of the earth, to the distance of that point from the centre.



Conceive a hole made through the earth, as represented in the adjoining figure, and a particle of matter at P below the surface. The shell or the quantity of matter more remote from the centre than P will have no moving influence upon it by the last proposition.

Now, let M represent the mass of the earth, and m the mass of the sphere below P. Also, let $CA=R$ and $CP=r$, and put F to represent the force of gravity at A, and f to represent the force of gravity at P.

Then by the theory of gravity we have

$$F : f :: \frac{M}{R^2} : \frac{m}{r^2}$$

By the measure of cubes, as taught in mensuration, we have

$M=qR^3$ and $m=qr^3$ q being the constant decimal ,5236 or one-sixth of 3,1416.

Now in the above proportion substitute the values of M and m, and reduce, and we shall find

$F : f :: R : r$ which proves the proposition.

must be taken as the unit. To make this principle clear, we give a few practical

EXAMPLES.

1. The force of gravity at the earth's surface is sufficient to make a body fall $16\frac{1}{12}$ feet, or 193 inches in the first second of time. What will be the force of gravity on the top of a mountain 3 miles high, the semi-diameter of the earth being 3956 miles?

By the theory of gravity we shall have the proportion

$$\text{As } \frac{1}{(3956)^2} : \frac{1}{(3959)^2} :: 193 : x$$

$$\text{Hence, } x = \frac{193(3956)^2}{(3959)^2} = 192.72 \text{ nearly.}$$

By this example we perceive that the force of gravity 3 miles above the surface of the earth, is nearly the same as at the surface, only a diminution of $\frac{28}{100}$ of an inch, or about $\frac{1}{700}$ of the whole. *Hence, at all accessible distances to us, the force of gravity may be considered as invariable.*

2. What is the force of gravity, or how far will a body fall the first second of time, let drop from 1000 miles above the earth's surface? *Ans.* 122,53 inches.

3. The distance to the moon is 60 times the semi-diameter of the earth, what then is the force of the earth's gravity on the moon?

By the theory we have

$$\text{As } \frac{1}{1} : \frac{1}{(60)^2} :: 193 : x$$

$$\text{Or } x = \frac{193}{3600} = 0,0536+$$

That is, the force of terrestrial gravity at the distance of the moon's orbit is sufficient to make a body fall but about $\frac{1}{50}$ part of an inch in one second of time.

But knowing the distance to the moon, and the time it takes to make a revolution round the earth, we can compute how far it must fall from a tangent line in a second, and the result of such computation corresponds with the computed fall of a body by gravity.

This evidence was irresistible, and the fall of the moon from the tangent of its orbit was ascribed to the force of the earth's attraction, and when the attracting force of

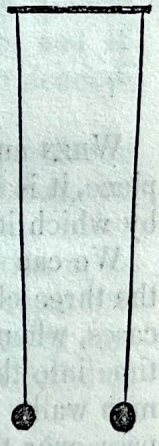
the moon was put into the computation, as it should have been by the theory of gravity, and a small correction made for the diminution of gravity caused by the rotation of the earth, the two computations agreed exactly.

Philosophers could now account for the tides of the ocean, for they followed and were influenced by the attraction of the moon; and, in short, the theory could at once account for all the common phenomena observed in the solar system, and thus the truth of the theory itself was seen and satisfactorily established.

The earth is a sphere, and attracts bodies towards its centre from all directions; hence it follows that *up* and *down* are only relative terms, and two plumb lines are not parallel, as all such lines meet at the centre of the earth; from this we perceive that plumb lines diverge as they ascend upwards, and of course walls and edifices constructed by the use of the plumb must widen towards the top, but any practical consideration of this would be far too wise, and justly expose the operator to ridicule.*

If matter attracts matter, as the theory of gravity asserts, two balls suspended near each other, as in (Fig. 2,) must be nearer together at bottom than at top, not merely because the two lines tend towards the same point, the centre of the earth, but because the two bodies attract each other. But, however large the two balls may be, their small masses *compared* with the great mass of the earth, must be unappreciable, unless we are prepared to measure the smallest conceivable variation.

Fig. 2.



Each ball must obey the attraction of the earth, and the earth's attraction is so much

* It is well known that great prejudice has always existed between theoretical, and practical men. Doubtless both as classes, are in fault. The former by their over-niceties and their propensities to cast doubts and demand proof of what every body knows. The latter for their real inattention and unappreciation of sound theoretical knowledge, and the consequent over-valuation of their own abilities, for such persons must judge of themselves by too low a standard. However, we have never found any really sound theoretical men who were over nice in practice; the engineer who corrects his few uneven short levels for the rotundity of the earth, and the navigator who keeps his reckoning to seconds, are not generally those who have a surplus of theoretical knowledge.

greater than the attraction of either ball, that their mutual attraction is lost in comparison.

A plumb line suspended by the side of a mountain does not tend exactly towards the centre of the earth, but inclines in by the attraction of the mountain, but the greatest variation claimed by observation is only eleven seconds of an arc.

It is said that the attraction of a large leaden ball may be made sensible, by means of a well-suspended horizontal bar, made to turn easily. Note the direction in which the bar has settled. Then carefully, (without violently disturbing the air,) bring the leaden ball sideways by the extremity of the rod; the rod will slightly change its position. If two balls are used, one at each extremity of rod, on opposite sides, the effect would be double.

Drift wood, on still water, will huddle together, and it is supposed by the mutual attraction of the different pieces. Cork, pith balls, and such other light material, on a basin of water, will be found together if undisturbed for any considerable time.

Chapter II.—Motion.

When any body or material point constantly changes place, it is said to be in motion, and the degree of rapidity by which it changes is termed velocity.

We can have no conception of motion independent of the three elements, *time*, *velocity*, and *distance;* and in all cases, when the velocity is uniform, the product of the time into the velocity will give the distance. Thus, if a man walks three miles per hour for four hours, he will pass over the distance of twelve miles. Here one hour is the unit for time, one mile is the unit for distance, and the velocity, in this and in every other case, is measured by the number of units of distance which the moving body changes place during *one unit* of time.

(Art. 1.) The units, both for time and distance, may be changed at pleasure. For time, we may take a second, minute, hour, day, week, month, year, or any other

period for the unit, and an inch, foot, yard, mile, or any other measure of distance for the unit of distance.

For a practical illustration of these principles, we give the following examples:*

1. If a body move 12 feet per second, how far will it move in 24 hours? *Ans.* $3\frac{3}{11}$ miles.

2. At the rate of 15 miles per day, how many days will it require to pass over 500 miles? *Ans.* $33\frac{1}{3}$ days.

3. If a planet move 4′ 10″ per day, how many days will it require to complete a revolution of 360°?

Ans. 5184 days.

We might go on and give examples without end, but a small number only are requisite, for examples of this kind do not teach principles, but serve to fix them in the mind when previously taught.

In the first of the preceding examples, the unit for distance was one foot, but in the answer it was given as one mile; thus, in the same problem we see that the units for time or distance may be changed at pleasure.

If the velocity of a moving body remains unchanged, the motion is said to be uniform; if the velocity becomes less and less, it is said to be *retarded* motion; if greater and greater it is said to be *accelerated* motion; and if greater and then less, or the converse, it is then denominated *variable* motion.

(Art. 2.) To compute the distance that a body will run over by accelerated, retarded, or variable motion, we must either obtain the average motion for the time under consideration, and thus reduce the variable motion to its equivalent uniform motion, or conceive the time separated into very small intervals, and determine the velocity corresponding to each interval, which may be considered as uniform during that short period of time.

(Art. 3.) By careful observation on bodies at rest and in motion, we discover the general property of

INERTIA.

By inertia is meant passiveness, or want of power, and

* Those pupils who, by their algebraical acquirements, clearly comprehend the universality and spirit of a symbolical expression, require few or no specific examples, for all problems of this nature are comprised in the equation

$$tv=d$$

in which the symbol t represents time, v velocity, and d distance.

it is common to all bodies, whether animate or inanimate; living beings, by the power of will and muscle, may change, counteract, or modify the effect of inertia, but inertia is still an inherent principle pertaining to matter. All experience teaches us that an inanimate body has no power to put itself in motion. Wherever it is placed, there it will remain until some external force moves it, or in other words, counteracts the inertia.

A body in motion has no more power to cease moving than it had to create the motion, and if the motion ceases, it is in obedience to some external force counteracting the inertia. The force of gravity, or the attraction of the earth near its surface, overcomes all other temporary forces, and brings all detached bodies to the ground and stops their motion. A body moving along a plane surface is disturbed by the friction of the surface, and from this cause, however small, it must finally come to rest, but the tendency of the motion itself is to continue, as the following considerations will illustrate:

If a ball be rolled along the rough surface of the ground it soon comes to rest by reason of the action of gravity, which presses it against the surface, and by the impediments it meets with, but let the impediments be removed, the ball and the surface both smooth, and the plane horizontal, the ball will continue in motion much longer and go much farther than in the first supposed case, as all experience confirms; and could we conceive of a perfect plane and a perfect void, and there a body in motion in perfect independence of gravity, electricity, friction, and all other external influences, we must admit it would move forever, for there can be no effect without a cause. We have the most perfect illustration of this truth in the motion of planets in the astronomical world, where bodies move through void space undisturbed by friction, and as far as we know, the simple law of inertia has and will perpetuate the motion from the beginning to the end of time.

We have sensible but less dignified illustrations of this law by the motion of a top, which continues to spin for a considerable time when every thing is in the most perfect order, as the resiting influences, the friction of the air and the friction at the resting point are small.

It is said that pendulums set in motion in an exhausted vessel, have been known to continue to vibrate for more than a day without the aid of clock-work, because there is little to resist the motion besides the friction at the point of suspension.

A person riding on horseback becomes painfully sensible of the law of inertia, if the horse suddenly and unexpectedly either increases or relaxes his motion. If the horse give a sudden and unanticipated spring in any direction, there will be a strong tendency to make a separation between himself and rider, as motion cannot be instantly communicated from one body to another, and the effect of inertia is to retain bodies in their present state, and therefore the body of the rider being inert, tends to remain in the same place, and the horse springs from under him.

If the horse is in rapid motion and stops short, the tendency of the rider is to continue in motion, and *inertia* will throw him forward over the saddle, and if the rupture is sufficiently great, it will throw the rider over the horse's head.

The same thing is experienced in the sudden changes of all kinds of motion. A boat striking the shore, or too suddenly impelled by any force, will experience more or less inconvenience or damage from this universal or invariable law of nature.

The more rapid the motion the more danger from its interruption. The disagreeable motion of a vessel in a storm, or rather the multitude of conflicting motions on the wave, and nearly all the accidents of moving vehicles on sea and land, arise from the necessity of obedience to this law of inertia.

(Art. 4.) When a body is in motion, it has no more power to change the *direction* of the motion than it has to change the amount of the motion or to create the motion. Hence it follows that motion is naturally in a right line, and if the direction is changed, it is in obedience to some other external force than the one that first impelled it; and from this arises the danger of making a short turn when moving rapidly. The *inertia* is in one direction—and if the impelling force, like the horses to a carriage,

is suddenly changed in quite a different direction, there is much danger of upsetting, as the law of inertia tends to impel the carriage in a right line in the direction of the former motion.

For this reason short curves on rail-roads are dangerous, and to counteract the danger, care is taken to run over them with diminished or moderate velocity, and the outer rail is a little elevated.

(Art. 5.) The force necessary to counteract the inertia of a moving body is called

MOMENTUM.

A mere material point or body, without mass, can have no momentum, however rapidly it may move, for it can exert no force when coming in contact with another body, a truth which can only be illustrated by a reference to the velocity of light, which moves at an inconceivably rapid rate, yet produces no external effect; but material substances, bodies having weight, when in motion produce a force which both reason and experiment proves to be a compound or product of their weight and velocity.

Momentum is only a relative term, and therefore it is no matter what the unit may be, if it is the same in relation to the several moving bodies immediately under consideration.

The momenta of two bodies of equal weight will be to each other as their velocities, and when the velocities are equal, the momenta will be as their weight.

If a body of 20 pounds weight move with a velocity of 16 feet per second, and another body of 30 pounds weight move with a velocity of 12 feet per second, then the momentum of the first is to that of the second as 320 is to 360, or as 32 to 36, or as 8 to 9.

If two bodies have the same momentum, which act in opposite directions, they will mutually counteract each other and become at rest. This principle will be frequently referred to when we treat on the mechanical powers.

If two bodies, as a ship and a boat, resting freely on water, be attached to each other by a cord, and a man in the boat pull on the cord, the ship and the boat will move towards each other with velocities in reciprocal proportion

to their weights. Thus, if the ship and all within it weigh 200 tons, and the boat and all within weighs 2 tons, the velocity of the boat will be 100 times that of the ship, and of course it will move 100 times as far. Such like results have been many times proved by experiments, and they are strictly conformable to reason.

To fix this principle in the mind, we give the following

EXAMPLES.

1. A body of the weight of 150, has a velocity of 5, what velocity must be given to a body whose weight is 35, to give it the same momentum as the first?

Ans. $21\frac{3}{7}$.

2. A body of the weight of 2000, has a velocity of 3; another of the weight of 800, has a velocity of 10, what are their relative momenta? *Ans.* As 3 to 4.

3. A body whose weight is B, has a velocity of V; another body has a weight expressed by b, and velocity x, what are their relative momenta? *Ans.* As BV to bx.

4. A body whose weight is B, and velocity V, what velocity shall be given to another body whose weight is b, that their momenta may be equal?

Ans. $\frac{BV}{b}$ velocity.

(Art. 6.) It is the first impression with young minds that motion is sensible, because they are sensible of the rough and imperfect motions of vehicles, cars, &c. with which we are acquainted, but this is all delusion; motion, true and perfect motion, is quite insensible to our nerves, it is the interruption of motion that makes it sensible.

A rough wagon moving over a rougher road is continually reminding the passengers that it is in motion; but on examination it will be found that it is the sudden changes of motion, the operation of the law of inertia, of which the passenger is so sensible; let the vehicle become more perfect, provided with springs, and the road become hard and smooth, and all painful sensation, at least, will vanish; and could we arrive at perfection in motion, it would become insensible to us when we are carried with it. This is nearly experienced when riding in a boat that is quietly floating down a gentle stream; and we have a perfect exemplification of this truth in

the motions of the earth itself. *We are all riding on that vehicle;* yet quite insensible of its motion, because the motion is perfect or uninterrupted.

(Art. 7.) The general laws of motion and inertia govern the descent of material bodies falling freely through void space by the

FORCE OF GRAVITY.

The force of gravity exerted at the surface of the earth by the earth's attraction can only be decided by *experiment.* If the earth were larger, contained more actual matter of the same degree of compactness, bodies would fall farther than they now do in the same interval of time. If the earth had been made to contain the same bulk it now does, and its density much greater, bodies would fall farther in the same time. If the density were less, the fall would be less,—hence we take the fall of bodies for the real and proper measure of the force of gravity; and, indeed, this is all we know of the standard and measure of gravity throughout our solar system.

The atmosphere resists and very much modifies the actual descent of bodies; but at present we must investigate the law of descent, independent of this resistance.

All are convinced by universal experience that any body taken above the earth's surface, and simply abandoned to its gravity, that is, *let drop from a state of rest,* the force of gravity will give it a certain velocity during the first interval of time, say one second. Now as we suppose there is no medium to impede the body, and no other force acting on the body, *by the law of inertia* the body must retain all the velocity during the second interval which it acquired in the first, and the continued action of gravity during the second interval is the same as during the first; hence, at the end of the second interval, the body will have double the velocity it had at the end of the first. During the third interval of time, the falling body must, by the law of inertia, retain all its previously acquired velocity, and the continued action of gravity will give it another additional velocity; therefore, at the end of the third interval, the falling body will have three times the velocity it had at the end of the first interval. Thus we may continue to reason through each

interval of time, and we shall find that each equal interval of time will give an equal additional velocity to the falling body—hence we have proved this general proposition, that

The velocity of falling bodies increases in proportion to the increase of the time.

But, by the universal laws of motion explained on the 20th page, the distance through which a body moves may be expressed by the time multiplied into the *mean* velocity. Now a body let fall from rest has *no* velocity at the beginning of the first interval, and has *some* velocity at the end of the interval, but as the velocity increases as the time, as just explained, the medium velocity for the whole interval will be half what it acquired at the end of the interval, and this will be true, whether the interval be small or great.

(Art. 8.) Let us now consider one second as the unit of time, and put v to represent the velocity acquired by a falling body at the end of the first second, then $2v$ will represent the velocity at the end of the 2d second, $3v$ the velocity at the end of the 3d second, $4v$ the velocity at the end of the 4th second, and so on.

Now as v is the velocity at the end of the 1st second, $\frac{1}{2}v$ will represent the mean velocity for the entire second, and reasoning in the same way, we shall find

$\frac{1}{2}v$ $\frac{1}{2}(2v)$ $\frac{1}{2}(3v)$ $\frac{1}{2}(4v)$ $\frac{1}{2}(5v)$ &c. for the mean velocities corresponding to the entire intervals of

1 2 3 4 5 &c. seconds.

But the distances passed over by the moving body must be its mean velocity multiplied by the time; therefore the corresponding distances must be

$\frac{1}{2}v$ $\frac{1}{2}(4v)$ $\frac{1}{2}(9v)$ $\frac{1}{2}(16v)$ $\frac{1}{2}(25v)$ &c. &c.

As $\frac{1}{2}$ and v are factors common to every term, these distances are to each other as

1 4 9 16 25 &c.

That is, *the distances passed over in the whole time of a body falling from rest, must be as the squares of the times.*

By taking the difference of these numbers, we perceive that the relative distances corresponding to each second, must be as the numbers

1 3 5 7 9 &c. a series in arithmetical progression whose first term is 1, and common difference 2.

But it is an *experimental fact*, independent of all reasoning, that a body falls $16\frac{1}{12}$ feet during the first second of time,

Therefore $\frac{1}{2}v=16\frac{1}{12}$ or $v=32\frac{1}{6}$ feet.

If we generalize the expressions for the distances of any fall by putting t to represent the time in seconds, and d to represent the distance in feet, we shall then have this general equation

$$\frac{1}{2}vt^2=d$$

As $\frac{1}{2}v=16\frac{1}{12}$ the distance any body falls during the first second of time, which may be considered as the measure of terrestrial gravity, therefore we may call it g, and the equation becomes

$$gt^2=d$$

As g is a known quantity, if either t or d is given in any problem the preceding equation readily gives the other, and solves the problem.

EXAMPLES.

1. How far will a body fall in 9 seconds?

Ans. $d=16\frac{1}{12}\times 81=1302\frac{3}{4}$ feet.

2. How far will a body fall in $3\frac{1}{2}$ seconds?

Ans. $d=16\frac{1}{12}\times\frac{49}{4}=197,+$ feet.

3. A body fell from the height of 240 feet, what was the time of the fall? *Ans.* $16\frac{1}{12}t^2=240$ 3,86+ sec.

4. A body fell during 7 seconds, how far did it fall in the last half second?

Find how far it fell in 7 seconds, then how far it fell in $6\frac{1}{2}$ seconds, and subtract one from the other.

Ans. 108,4+ feet.

5. A pebble let drop from a tower was observed to strike the ground in 5 seconds (on the supposition of no atmospheric resistance.) What was the height of the tower? *Ans.* $16\frac{1}{12}\times 25$ feet.

6. How long must a body fall to generate a velocity of 100 feet per second?

As the velocity increases as the time, and as experiment shows a velocity of $32\frac{1}{2}$ feet at the end of the first

seeond, therefore for a solution of the last example, we have

As $32\frac{1}{6} : 100 :: 1 : t$ or $t=\frac{600}{193}=3.11$ seconds nearly.

7. How long must a body fall to generate a velocity of 1 mile per second, and how far must it fall?

Ans. $164\frac{21}{193}$ seconds. It would fall $82\frac{4}{193}$ miles.

(Art. 9.) Gravity always acts in one direction, perpendicular to the surface of the earth, and it will generate equal velocities in equal times, and the force will be equally efficacious, whether it acts on a body *descending* or *ascending;* therefore, if a body be projected upwards, gravity will diminish its velocity $32\frac{1}{6}$ feet in the first second of time, $64\frac{1}{3}$ feet in two seconds, &c.; hence gravity will finally bring the body to rest, and cause its return, and the law of *ascent* is the same as the law of *descent*, except the inverse order, and the velocity of a body is the same at the same height in both ascending and descending.

To fix this principle in the minds of the learners, we give the following

EXAMPLES.

1. What velocity must be given to a body to make it ascend 300 feet?

Ans. It must start with the same velocity that a body would acquire by falling 300 feet. Hence, the general equation for falling bodies, (Art. 8.) Or $gt^2=d$ will give the time required for a body to fall 300 feet, and this time multiplied by $32\frac{1}{6}$ will give the velocity required.

Therefore $16\frac{1}{12}t^2=300$ or $t^2=\frac{3600}{193}$ or $t=\frac{60}{\sqrt{193}}$

Finally $\frac{60}{\sqrt{193}}\times\frac{193}{6}=10\sqrt{193}=138{,}924+$ feet per second, the velocity required.

2. What velocity must be given to a body to make it rise 100 feet?

Ans. It must start at the rate of 80.21+ ft. per second.

3. What velocity must be given to a body to make it ascend 500 feet?

Ans. The same velocity it would acquire by falling 500 feet, and the arithmetical answer is 179.3 ft. per second.

4. To what height would a body rise, if projected upwards at the rate of 120 feet per second?

First find the time requisite for a falling body to acquire a velocity of 120 feet per second. Then the square of this time in seconds, multiplied by $16\frac{1}{12}$ feet will give 223,83 feet for the height required.

Operation $t^2=\frac{120\times6\times120\times6}{193\times193}$ Hence $d=\frac{120.6.120.6}{193.193}\times\frac{193}{12}=\frac{43200}{193}=223.83+$

All these examples are on the supposition that the moving body experiences no resistance from the atmosphere, and as this supposition is not true, these results are not true; but how far they may differ from truth will be a subject of special investigation in a subsequent article.

(Art. 10.) The force of gravity must have its full effect whether acting alone or with other forces, and indeed every force must have its effect, whatever number of forces act together or against each other.*

When two or more forces act in different directions, the body must obey both, or the result of the whole, and move in a midway direction between them. But the investigation of this subject we must defer until we come to the next chapter.

(Art. 11.) It is a common impression that some bodies will fall more rapidly than others, and that larger masses of the same body will fall quicker than smaller masses—as for example, some persons, without investigation, might decide that ten pounds of lead would fall quicker than one pound, while others might say that one pound, or a small leaden ball, would fall most rapidly. But take away the resistance of the air, and all bodies, and all masses of the same body will fall with equal rapidity.

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* If in place of a body being let drop from a state of rest, an impulse be given it, the body will fall with that additional impulse, and by the law of inertia, (Art. 3,) the additional impulse must give it a constant velocity, in addition to the velocity generated by gravity, and thererore, if a represents the velocity from the given impulse, the formula for problems under such circumstances must be

$$at+gt^2=d$$

In this equation g is always known, and when d and a are given and t required, we have a common quadratic equation. The teacher can give examples.

For each and every body is acted upon by the *same* force, the mass of the earth, and the same force will always produce the same effect; hence, if there be no resistance, every body will fall the same distance in the same time, *unless the mass of the falling body itself gives additional force;* and this is true, bodies do approach each other by the force of their *mutual attraction*, but the mutual attraction of the earth and 1 pound is the same to our senses as the attraction of the earth and 10, 100, or 1000 pounds. The comparative addition, great as it may be, *is nothing;* the same as a quart, a gallon, a barrel, or 1000 barrels of water are equally nothing, thrown into the sea.

To give a more definite illustration of this subject, let us suppose one pound and ten pounds let drop from the same height at the same time. The gravity of the earth acts on the pound and causes it to fall, it also acts on every pound of the ten pounds, the same as though each pound was separate, and there is ten times as much attraction exerted on the ten pound body as there is on the one pound body, but it requires ten times as much force to move ten pounds as to move one pound, therefore the two bodies will move with the same velocity, and of course fall the same distance in the same time, but the *momentum* or absolute quantity of motion is ten times as great in the larger as in the smaller body.

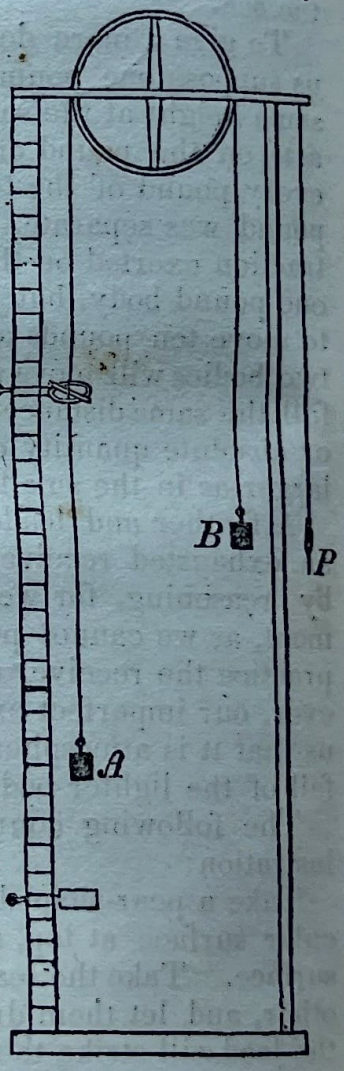
A feather and leaden ball will fall in the same time in an exhausted receiver, but we must be convinced of this by reasoning, for we never can make a perfect experiment, as we cannot perfectly exhaust a receiver, and for practice the receiver cannot be of sufficient height; however, our imperfect experiments are sufficient to convince us that it is atmospherical resistance only that retards the fall of the lighter bodies.

The following course of experiments may be some illustration:

Take a pear-shaped mass of lead with a little flat circular surface at top, and cut a piece of paper to fit that surface. Take the lead in one hand and the paper in the other, and let them drop from any convenient elevation, the lead will strike the ground first. Now place the paper

upon the lead, not so as positively to adhere, and let them fall, they will keep together, since the lead removes the air from under the paper, its resistance to the paper is taken away, and both bodies fall together.

We cannot make accurate experiments on falling bodies without resorting to artifice, owing to the swiftness of descent. The mathematical relation which exists between the length of a pendulum which vibrates seconds, and the distance a body will fall in a second, and which will be explained hereafter, is the only accurate method of showing us the real force of gravity, for both the time of vibration and the length of the pendulum can be very accurately determined. But more simple and striking experiments can be made by *Atwood's machine*, which is represented in the adjoining cut.



This machine consists of two upright posts with cross pieces and wheel at the top, as shown in the figure. The equal weights *A* and *B* are connected by a thread over the wheel. One post is accurately graduated to feet and tenths. A movable ring and a stage or plate to arrest the weight at any desired point, are made to slide up and down, and by means of screws can be fastened at any point on the graduated post. The weight *A* passes through the ring, and the ring takes off, and is designed to take off, any additional weight which may be put on *A*, to set the weights in motion. The plate is designed to arrest the motion of the weight *A* at any desired point. A pendulum *P* is connected to measure equal intervals of time. The experiments made by this machine will not show perfect results unless we can remove all the friction of the wheel, and are in

every respect skilful and accurate, but we all know that in practice there can be no perfection. However, the experiments with the machine accord remarkably well with theory, sufficiently so to establish all the essential truths of the theory.

From one and the same experiment with this machine, we can deduce several of the laws of motion.

For the sake of perspicuity, each of the weights *A* and *B* are made $31\frac{1}{2}$ times heavier than the weight designed to be placed on *A* to set the weights in motion; then the whole mass in motion must be $31\frac{1}{2} \times 2 + 1 = 64$.

EXPERIMENT.

Bring *A* to 0 on the graduated scale, and set the ring at 48 inches and the stage at 8 or 10 feet. Place the small weight on *A*, and draw aside the pendulum. Let go the thread and pendulum at the same instant. At one vibration of the pendulum, *A* will have descended 3 inches, at two vibrations 12 inches, at three vibrations 27 inches, and at four vibrations 48 inches; here *A* will go through the ring, which will take off the weight which was put on *A*, and after this *A* will descend with a uniform motion until it stops on the stage.

If the small weight had not been put upon *A*, but dropt above, it would have descended to the floor almost instantly, but as *A* and *B* all the while balance each other, it might be inferred that the small weight would fall as quickly attached to *A* as above.

But the *fact* that it only descends with one sixty-fourth part of the velocity, shows

1st. *That matter is inert.* Although *A* and *B* exactly balance, it requires force to put them in motion, and the force of gravity exerted on one ounce or one pound, is distributed over 64 ounces or pounds, and the motion of the whole is $\frac{1}{64}$ of what it would be on one.

2d. It also proves that *momentum is equal to the weight multiplied by the velocity*, for as we increase the weight of the body moved, we diminish the velocity in the same proportion, (the same force acting.)

3d. The experiment shows that gravity increases the velocity in proportion to the time acting, and the whole distance as the square of the time.

4th. The *experiment* illustrates the theory of uniform motion, for after the small weight is left on the ring, gravity ceases to act, and, *comparatively speaking*, there is nothing to disturb the already acquired motions of *A* and *B*, and in fact, they do move uniformly until brought to rest on the stage.

5th. If different weights be put on *A*, the rapidity of the descent will be in proportion to the additional weight, thus proving another law of motion, that the velocity is in proportion to the force.

The full development of the theory of gravity makes the universe talk, but it is impossible to give a full development in a work like this, and we dismiss the subject for the present with the following proposition:

(Art. 12.) *Two bodies equally attract each other, whatever be their relative masses, but the visible effect as measured by distance or velocity, will be reciprocal to their masses.*

For instance, the mass or weight of the earth is 75 times the mass of the moon, and the moon attracts the earth as much as the earth attracts the moon. To illustrate this, conceive the earth divided into 75 equal parts, each equal in weight to that of the moon, each one of these equal parts will attract the moon, and the moon will attract each one of these equal parts as much as it is attracted by it; therefore the moon attracts the earth as much as the earth attracts the moon; but the *effect* of the moon's attraction on the earth is diffused over 75 masses, and the earth's attraction on the moon is all concentrated in one mass, and the consequent motion of the small mass must be proportionably greater.

This principle is every where recognized throughout the planetary system. Two planets mutually and equally attract each other, but the apparent disturbing effect is always observed to be greater on the smaller body, and their relative apparent disturbances will at once show the relative masses of the planets.

Chapter III.—Resistance to motion—action and reaction—compound motion—reflected motion—curvilinear motion—circular motion.

(Art. 13.) As no two bodies can occupy the same space in the same time, therefore any body passing through air, water, or any other medium, must push the particles of the medium aside to make way for itself, and the force thus lost is called resistance.

To give a clear illustration, we may imagine a boat passing through the water at the rate of one mile per hour, it must move out of its path a certain quantity of water which will require a certain, and as yet, *indefinite force*.

Now suppose the boat moves two miles per hour, *twice* as much water must be displaced, which will require *twice* as much force, but *each* particle of water must be moved with double the velocity as in the first supposition, and on this account we must again double the force. That is, we must double the force, because there are twice as many particles of water to displace, and double this product, because each particle must be displaced with twice the rapidity as in the first instance. Hence, a body moving with a velocity of 2, will meet with 4 times the resistance as with a velocity of 1.

If the boat should move 3 miles per hour, it would have 3 times as much water to displace as moving 1 mile, and this would require three times the force—but each particle of water must be moved with 3 times the rapidity, and this again will require the last force to be multiplied by 3, making 9 times the opposing force as when the velocity was 1.

In this manner we might reason on indefinitely, and we shall find that if

1 2 3 4 5 6 7 &c. represent

the velocity of a moving body, the resistance it meets with, if any, will be in proportion to the numbers

1 4 9 16 25 36 49 &c. that is,

That the resistance will be as the squares of the velocities.

This will account for the fact that the least motion of the air will put a ship in motion, a very light breeze little more than perceptible, will cause her to sail between two and three miles an hour; a gentle breeze will drive her four miles an hour; a fresh breeze, six miles an hour; a strong breeze, only seven or eight; a gale, nine or ten. and no force of the wind will drive a common vessel with usual lading, over twelve, or at most, thirteen miles per hour. The resistance which was very little with the very slow motion, has increased with the square of the velocity, and now it has become so great as to endanger the safety of the vessel, and should it venture to sail longer, it would be torn to pieces or plunged under the billow, but could not make its way through the water at a greater speed; hence, under such circumstances, sails are furled to let the force of the wind pass by, and all efforts are directed to the safety of the ship alone.

From this philosophical principle we learn that the utmost speed of a steamboat cannot be much above ordinary rates, and that one of these vessels can be driven at a slow rate with but a fraction of the wear and tear, and expense, for fuel of the common rates.

Bodies falling through the atmosphere are resisted in proportion to the particles of air necessary to be removed. A ball of cork and another of lead, of the same diameter, will meet with the same resistance in falling from the same height, but the leaden ball has more power to overcome the resistance than the cork, and hence the effect is not so apparent.

When a heavy body, like iron or lead, commences to fall, during the first quarter or half second, the resistance of the atmosphere is very trifling, but the velocity increases as the time, (Art. 8,) that is, the velocity increases as the numbers 1 2 3 4 5 &c. but the resistance we have just seen increases as the square of the velocities; that is, as the numbers 1 4 9 16 &c. the resistance increasing faster than the velocity, therefore the increasing resistance must finally overcome the increasing velocity, or at least become equal to it, and after that the velocity can receive no farther increase, and of course becomes uniform.

This may be observed in the fall of light bodies; the velocity increases fast at first, but soon becomes uniform; a feather, falling in still air, would soon find its uniform motion; a cork body would acquire more velocity before it became uniform, and so on, the more dense the falling body the more power it has to overcome resistance, and the greater will its final uniform velocity be; but it is impossible to decide what that velocity will be, expressed in numbers, for it will be different with every different substance, and it will also depend on the shape of the falling body, on the same principle that the sailing of a ship will in a great measure depend on the shape of the vessel.

From the foregoing facts and considerations we learn that the problems under Art. 8, can only be approximations to the truth, and there will be less and less of error as the time is shorter and the falling body more pointed and ponderous, and we further learn that it is idle to compute the distance through which hail stones have fallen from any supposed or real velocity with which they may have struck the ground.

This principle is very important in practical gunnery; "so great is the effect of the resistance, (says Dr. Hutton) of the air to the projectiles of considerable velocity, that some of those which in the air range only 2 and 3 miles at the most, would in a vacuum range about ten times as far, or between 20 and 30 miles.

The effects of this resistance are also various, according to the velocity, the diameter, and the weight of the projectile, so that the experiment made with one size ball or shell, will not serve for another size, though the velocity should be the same."

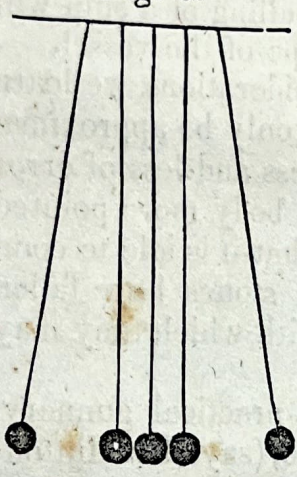
(Art. 14.) *Action and reaction are equal and contrary.* Bodies, of themselves, are perfectly passive, and if we press against a body with any force, the body must either give way in motion, or resist the force, and this resistance of force we call reaction, but it can resist with no more and no less force than that pressed upon it, for any other supposition would make the resisting body the creator or annihilator of force, which is contrary to the law of inertia.

A boatman pressing against the bank with his oar gives

motion to his boat in the opposite direction from that which he exerted force. A man rowing a boat, the *action* at one end of the oar is followed by *reaction* at the other. A bird beating the air with its wings causes a reaction, and if the reaction is greater than the weight of its body, the bird rises with the difference, and we perceive at once that rowing, flying, and swimming, are illustrations of the principle of reaction.

But the best experimental illustration of the equality of *action* and *reaction*, is given by a number of ivory balls suspended (as represented in the figure) so as just to touch each other. If one of the extreme balls be drawn aside, and let fall directly against the next, the force will pass through the whole series, and the other extreme ball that has nothing to act against, will fly out as far as the first ball fell. When the experiment is perfectly made, (which is a rare case,) none but the extreme balls move, for the action on the first ball struck is exactly counteracted by the reaction of the next, and so on through the series, and the fact that the centre balls do not move, give an experimental proof that action and reaction are equal.

Fig. 5.



The reaction of the water against the rudder of a ship guides the vessel. The reaction of gas (created by combustion) against the cannon throws the ball; and a similar reaction of the air propels the rocket in its flight.

Dr. Arnott tells us of a man who attempted to sail his pleasure boat by manufacturing a breeze from a bellows placed near the stern, to act on the sail. But on making the experiment, the boat went backwards rather than forwards, as the reaction of the atmosphere against the current from the bellows, before it reached the sail, was in that direction. Had the sail received the whole force of the wind from the bellows there would have been no motion at all, for the action and reaction would have been equal, and in contrary directions. Had he used no sail and turned his bellows astern against the atmosphere, the

reaction of the atmosphere would have propelled the boat; but a far more efficacious reaction could be produced by operating against the water in place of the air.

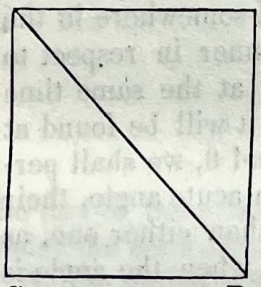
A force which begins and ends with a machine, has no power to move it, for the action at one point will be counteracted by the reaction at another; hence it is idle to think of making the long-sought *perpetual motion*, or self-moving machine.

COMPOUND MOTION.

(Art. 15.) A body acted upon by two or more forces at the same time, cannot remain passive, and there is no reason why it should obey one force more than another; in fact, it must obey the united or resultant action of all, and this is called *compound motion*.

Prop. 1. *If two equal forces, at right angles to each other, act at the same time on a body, the body must describe the diagonal of a square.*

Fig. 6.



Let AB represent the direction and magnitude of one force, and AC the other, then by the union of the two forces the body will describe the line AD, and at the end of the time will be found at D.

It would be absurd to suppose the body could disregard the force AC, and move along AB, or disregard AB and move along AC; and it would be equally absurd to suppose the body could tend to approach one line more than the other, and still more absurd to suppose that it could remain at rest; hence we prove that it must move along the line AD, as all other suppositions are absurd.

Now as the force AB must have its full effect on the moving body, it must carry the body as far as the line BD, and as the force AC must have its full effect, it will carry the body as far as the line CD; therefore, at the the end of the time when the forces have had their effect, the body will be at D.

This proposition can be imperfectly represented by experiment. Let equal weights draw cords over pulleys, one at the side, the other at the end of a table, the body

being at the junction of the cords and held by the fingers; when the tension of the cords are adjusted against the body, let it go, it will run off in a diagonal between the cords.

Prop. 2. *If the two forces AB and AC are unequal and not at right angles, as* (Fig. 7) and (Fig. 8), *the body will still describe the diagonal AD of the parallelograms*, and the resultant is called the principle of the parallelogram of forces.

Fig. 7.

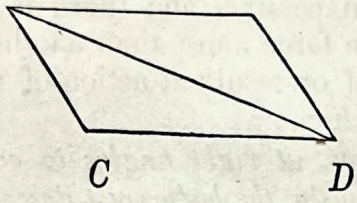
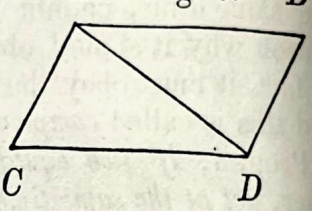


Fig. 8.



As the force *AB* must have its full effect and carry the body the distance of *AB* from the line *AC*, the body at the end of the given time will be found somewhere in the line *BD*. Reasoning in the same manner in respect to the force *AC*, the body will be found at the same time somewhere in the line *CD*; therefore it will be found at *D*. By inspecting the two figures, 7 and 8, we shall perceive that when the two forces form an acute angle, their united action, or *resultant*, is greater than either one, as in some degree they act together; but when the angle is obtuse, as in Fig. 8, the resultant will be less, as one force partially acts in opposition to the other.

When we know that a body moves under the influence of two forces, and we have the resultant and one of the forces, we can obtain the other. That is, if we have *AD* and *AB*, we shall have *AC* also, for we can join *BD*, and *AC* is equal and parallel to it.

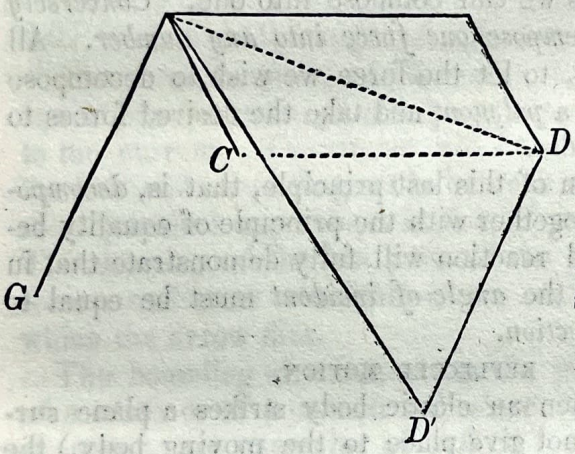
AD can be a diagonal of a great number of parallelograms; hence, when a body is observed to move in a right line, we may conceive it to be the result of two forces which form the sides of a parallelogram, and so to decompose it is called the *decomposition of forces*.

Prop. 3. *Three or more forces acting on a body at the same time, can be resolved into one on the principle of the parallelogram of forces.*

To effect this, take two of the forces and resolve them into one by the last proposition. Take that resultant as a single force with one of the remaining forces, and resolve them into one,—this last resultant and a remaining force, and resolve them into one, and so continue until all the forces shall have been used; the last resultant will be the compound resultant for all the forces.

For example, suppose a body at A to be acted upon by three forces at once. The first, AB, will carry the body from A to B in one minute; the second alone would carry the body from A to C in the same time; and the third will carry it from A to G; where will the body be at the end of the minute, and in what direction will it move under the compound influence of the three forces?

Fig. 9.



By the united influence of AB and AC, the body would describe AD. Now let AD represent one force, and AG another, and their united influence will give the resultant AD'. That is, the body will move along the line AD' during the minute.

This last resultant may be found more directly thus:—Conceive the body to obey one force at a time, that is, run along the line AB; then obey the force AC by running along the line BD, which is supposed equal and parallel to AC; then obey the force AG by running along the line DD', which is supposed equal and parallel to AG. This supposition would find the point D'. But by the nature of forces and the law of *inertia*, a body cannot obey simultaneous forces in successive times and pass round corners; it must move along the line AD', and this last method of finding the line AD' is called the principle of the *polygon of forces*.

By this last proposition it will be seen that we can find the resultant of any number of forces, by making each force in magnitude and direction, the side of a polygon. After all the forces are thus used, a line drawn from the first point to the extremity of the last side will represent the magnitude and direction of the resultant force. If the forces come round to the same point, the body would remain at rest under their united influence.

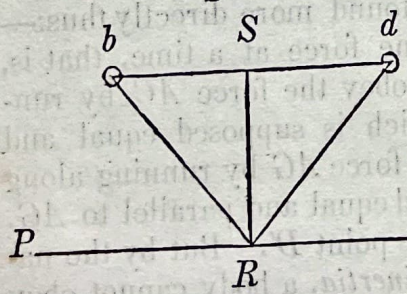
The converse of this proposition must be true; any number of forces we can compose into one. *Conversely then, we can decompose one force into any number.* All we have to do is, to let the force we wish to decompose form one side of a *polygon*, and take the desired forces to form the other sides.

The application of this last principle, that is, *decomposition of forces*, together with the principle of equality between action and reaction will fully demonstrate that in reflected motion the *angle of incident* must be equal to the *angle of reflection.*

REFLECTED MOTION.

(Art. 16.) When an elastic body strikes a plane surface, (that will not give place to the moving body,) the reaction of the plane throws the body off in a line having the same inclination to the plane as the line by which the body advanced, and this is called reflected motion. It is quite familiar to every person, and the chief skill, in addition to activity, in playing ball or billiards, is to possess a delicate sense of this law of motion.

Fig. 10.



Let PQ represent a plane, and b a ball thrown against the plane at R. It will fly off in the line Rd. The ball b strikes the plane with a certain force, which is represented by the line bR. Decompose this force into the two forces bS and SR, the first parallel to the plane, the last perpendicular to it. The first cannot be disturbed by the plane, and by the law of inertia, will continue and describe the line Sd, equal to

bS, and in an equal interval of time. The force *SR* perpendicular to the plane causes an equal *reaction* by the plane, and hence the body, the moment it strikes at *R*, is under the influence of two forces *RS* and *Sd*, and hence, by (Prop. 2,) Art. 15, the body must move in the line *Rd*. Now as $bS=Sd$, and *SR* common to the two triangles, and the angles at *S* right angles, the two triangles are equal, and the angle at *b* is equal to the angle at *d*. But the angle at *b* is equal to its alternate angle *bRP*, and the angle *d* is equal to *dRQ*; therefore the angle of *incident bRP* is equal to the angle of *reflection dRQ*.

The common practical illustration of compound motion is that of a boat attempting to cross a stream at right angles to the current. The stream will have its influence, and the boat will move diagonally between the forces; but the most practical experiment is that of the *bow and arrow*. The drawing of the two parts of the string are the two forces, and their resultant is the midway direction in which the arrow flies.

The bounding of a ball along the plane, the skipping of a stone or of a cannon ball along the smooth surface of water, are examples of reflected motion. But the most perfect example of the combined effects of resistance, reflected motion, and the decomposition of forces, is *that of making a ship work its way against the wind, when the wind itself is used as the moving force.*

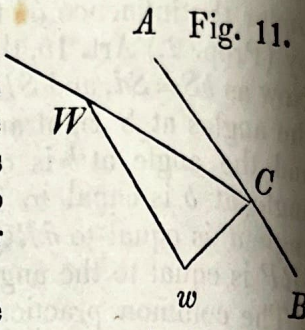
This will be recognised as possible, provided we show the possibility of sailing within a right angle to the direction of the wind. Thus, suppose the wind blew directly from the north, and then if a vessel could sail a little to the northward of east, and after making about two miles of distance, *tacking* ship and sail a little to the northward of west, and when about two miles on the westward tack, it is plain that the vessel would be north of the place first sailed from, and thus by sailing eastward and westward, crowding as close to the northward as possible, the vessel would work towards the north, provided it could really sail within a right angle to the wind, but not otherwise.

Now we are to examine the possibility of this condition. To have a clear conception of this whole matter, we must clearly bring it to mind that the force of the wind against

any plane surface, as the side of a house, the side of a barn, or on a sail, is perpendicular to the surface, however obliquely the wind may strike.

Let *AB* represent any plane surface, and *WC* a line of wind striking oblique upon it. This line of wind or force *WC* can be decomposed into the two forces *Ww* and *wC*, the first parallel to the plane, the last perpendicular to it.

Fig. 11.



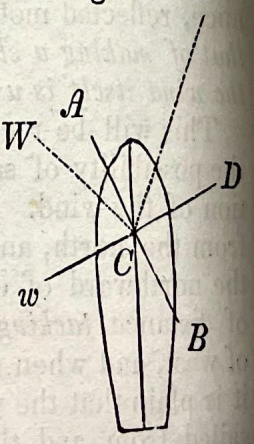
The first force *Ww* can have no effect on the plane, and the plane can only be effected by the force *wC*, which is perpendicular to it.

If the wind is very oblique, the perpendicular force *wC* will be much reduced; that is, much less than *WC*, the real force of the wind.

Now if *AB* is a moving surface like a sail, and it is made to keep the same position to the wind, the effect of the wind will be the same as though it blew in the direction *wC* with a diminished force, in place of blowing in the direction *WC* with its full force.

To apply this, conceive a vessel as represented in the adjoining cut, *AB* the position of the sails, and *WC* the direction of the wind. The effective force of the wind against the sails will be in the direction *wC*, tending to drive the vessel towards *D*. But the vessel cuts deep into the water, and the *resistance* of the water is five or six times as great sideways as it is forwards. In consequence of this, the vessel glides off in the direction *CE*, and the angle *WCE* is much less than a right angle.

Fig. 12.



Thus a vessel can sail away from a lee shore unless the wind is so very violent that she cannot carry sail. In such cases she must drift, and if she strikes the shore, may be wrecked.

(Art. 17.) Constant velocities, however great the number,

produce motion in a right line, as we have shown in (Art. 15); but when any one of the velocities become *variable*, the resultant motion would become a curve, and thus we have

CURVILINEAR MOTION.

We require no new principle to explain curvilinear motion; the fact that a moving body must fully obey two forces at one and the same time, will be found sufficient.

A single projectile force in any other direction than *up* and *down*, combined with the force of gravity, will produce curvilinear motion.

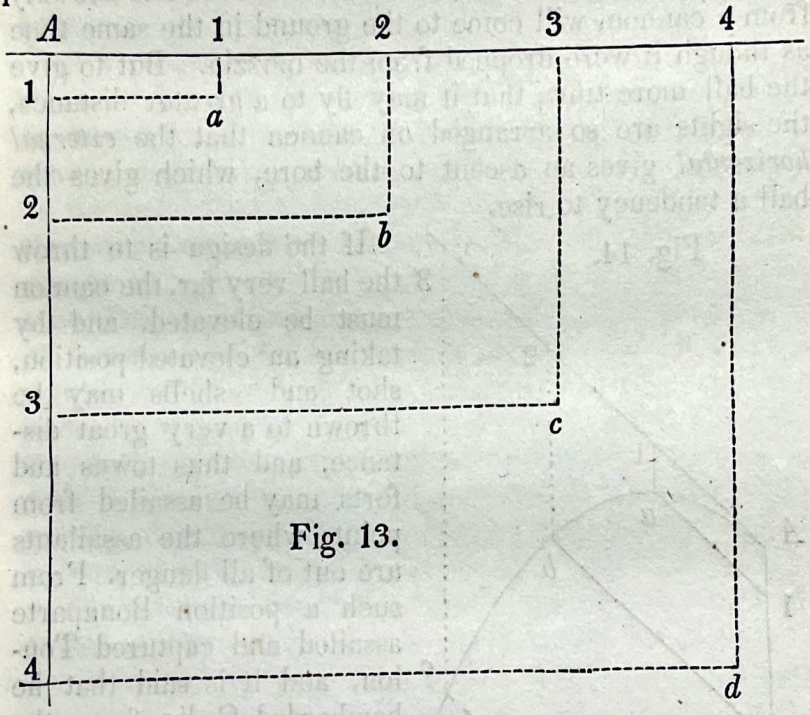


Fig. 13.

Let *A* represent a body projected horizontally, and by the force of projection and the law of *inertia*, it would be at the points 1 2 3 4 &c., equal distances from *A* in one, two, three, &c. seconds of time. Also, by the force of gravity, at the end of the first second it would be at 1, in the perpendicular line; at the end of the 2d second it would be at 2, &c.

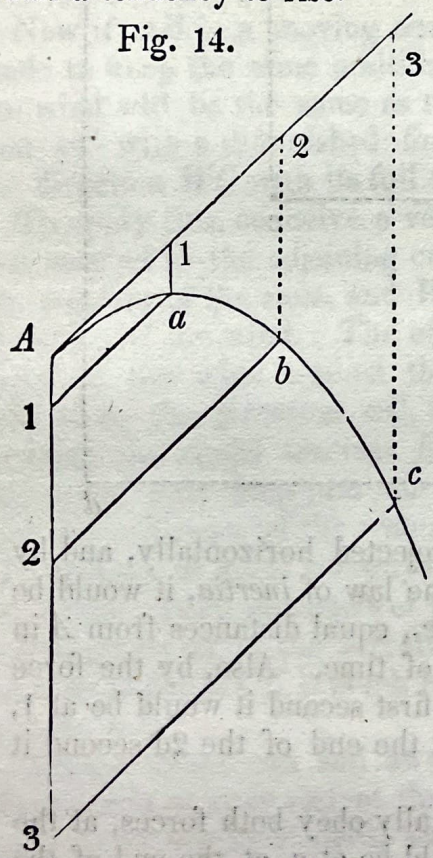
Now as the body must equally obey both forces, at the end of the 1st second it would be at *a*, at the end of the 2d second it would be at *b*, end of the 3d second at *c*, &c.

But these points are not in the same right line, and if we divide the time into half seconds, we shall have other points through which the body must pass, and by *infinite small* division of the time, we should have an infinite number of points, and their connection would make a *curve*.

We have examples of such a curve in water spouting horizontally from the side of a vessel. The curve line formed by the motion of a stone thrown through the air, is determined and governed by the same laws of motion.

As a body must obey all the forces acting upon it in the same time; it follows that a cannon ball fired horizontally from a cannon, will come to the ground in the same time as though it were dropped from the muzzle. But to give the ball more time, that it may fly to a greater distance, the sights are so arranged on cannon that the *external horizontal* gives an ascent to the bore, which gives the ball a tendency to rise.

Fig. 14.



If the design is to throw the ball very far, the cannon must be elevated, and by taking an elevated position, shot and shells may be thrown to a very great distance, and thus towns and forts may be assailed from points where the assailants are out of all danger. From such a position Bonaparte assailed and captured Toulon, and it is said that he bombarded Cadiz from the distance of more than five miles.

To show the appearance of the curve when a projectile is thrown at an elevation, we simply exhibit Fig. 14, and we can reason upon it just the same as we did on Fig. 13, the projectile at the end of each second will be at the extremity of the parallelograms, at *a*, *b*, *c*, &c. and

the distance 1*a*, 2*b*, 3*c*, &c. will be to each other as 1, 4, 9, &c. the squares of 1, 2, 3, and the curve is called a *parabola*, for it is the same as can be made by a plane cutting a cone *parallel* to its side.

(Art. 18.) The real curve made by a projectile through the atmosphere, is somewhat different from the theoretical curve, for the resistance of the atmosphere does not take instant effect. In the line of projection, it accumulates rapidly at first (as by compression) and then relaxes, which causes a variable motion, and in a perpendicular direction the resistance accumulates as the square of the time.

The combination of the same two forces keeps the moon in its orbit, and the reason why it does not descend to the earth, like other projectiles, is because the force of gravity upon it is only $\frac{1}{3600}$ part of the force of gravity on the earth, and it is entirely beyond the resistance of the earth's atmosphere. It is true that it sometimes comes nearer to, and at other times recedes to a greater distance from the earth than its mean, but such are the laws of motion, that the force of *inertia* to carry it off in a right line in which it is moving, *varies* faster than the variation of gravity caused by distance, and this enables it to bear external forces and perturbations, and if such, draw it too far out, it is brought back by preponderating gravity, or if it comes too far in, its more rapid projectile velocity throws it out.

The remarks that we have just made in relation to the moon, equally apply to the motions of the earth and the planets, which are retained in their orbits by *solar gravity*.

CIRCULAR MOTION.

(Art. 19.) We have seen by the law of inertia, that bodies moving under the impulse of a single force, must move in a right line, and bodies moving under the combined influence of projection and gravity describe *parabolic* curves—and hence all bodies that move in circles, are constrained to do so, by being fixed to their centers, from which there is a constant tendency to fly off, and the more so as the motion is the more rapid. The force necessary to keep the body in a circle is called the

centripetal force, and the corresponding force at right angles, is called the *centrifugal force*.

If we attach a ball to one end of a string, and take the other end between the thumb and finger, and give it motion, the ball will draw on the string, and the more rapidly we whirl it, the stronger it will draw; and if the string breaks, or we let it go, the ball will fly off in a right line from the point from which it was released.

On this principle boys sling stones, and before the invention of fire arms, and even now, among the Arabs, stones are thrown in this manner with great force and effect.

Water flying from a grind-stone, when it is turned rapidly; the mud flying from a coach wheel, and the ascent of water round the sides of a basin when it is set whirling, are all illustrations of centrifugal force.

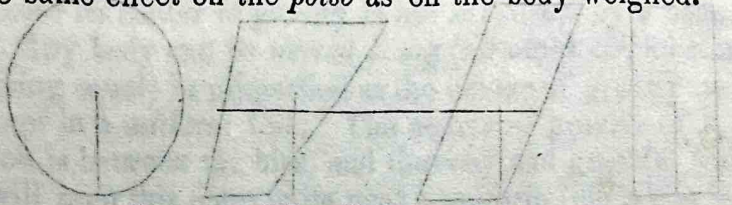
The surface of the earth has a circular motion on its axis, and the *centrifugal force* diminishes the power of gravity, and gives the earth a little different shape from that it would otherwise have. It bulges out, so to speak, at the equator, and contracts at the poles,—so that the equatorial diameter is about 26 miles larger than the polar. This may be illustrated by running a wire through a thin elastic circular band of tin or copper, and giving the band a rapid circular motion on the wire as an axis. The band will change its circular shape, swell out at its equator and contract at its poles, and more and less so in proportion to the rapidity of the motion.

The centrifugal force arising from the earth's motion on its axis, diminishes gravity at the equator by its $\frac{1}{289}$th part. That is, 289 pounds at the equator would be 290 at the poles, if this cause alone affected gravity. But besides this direct effect of the rotation of the earth, the centrifugal force produces an elipticity in the form of the earth itself, and this variation of form produces a variation in gravity between different portions of the surface of the earth, for a sphere is the only figure which has equal attraction on all parts of its surface. To make the computation of the difference of attraction at the equator and at the poles, arising from the peculiar figure of the earth, is a complex problem of some difficulty, but it has

often been computed, and the uniform result has given an increase of about $\frac{1}{5\,9\,0}$th part of the gravity at the equator for the gravity at the poles.

But the increase arising from the centrifugal force is easily computed, and is, as before observed $\frac{1}{2\,8\,9}$, to which we must add $\frac{1}{5\,9\,0}$, and their sum is very near $\frac{1}{1\,9\,4}$, which is, both by theory and observation, the ratio of the increase of gravity at the poles.

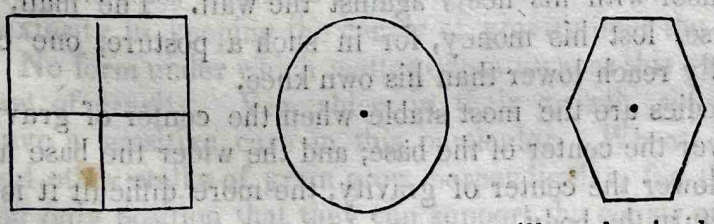
To understand this more clearly, we may say 194 pounds at the equator will press 195 pounds at the poles, as measured by a spring-balance, or by the vibration of a pendulum. The common mode of weighing will show no difference, as the common mode is only balancing one body by an equal weight of another, and gravity will have the same effect on the *poise* as on the body weighed.



Chapter IV.—Center of gravity.

(Art. 20.) *The center of gravity is that point in any body at which all its gravity appears to be concentrated, or that point on which it will exactly balance.*

From this definition it is at once apparent that the center of gravity of any mathematical figure of equal breadth and depth from end to end, must be at the center of the body; for instance, circles, squares, parallelograms, pentagons, octagons, &c. must have their centers of gravity at the center of the figure; but to find the center of gravity of other bodies, of more irregular shape, or of bodies formed of different kinds of material, requires more consideration and deeper investigation.



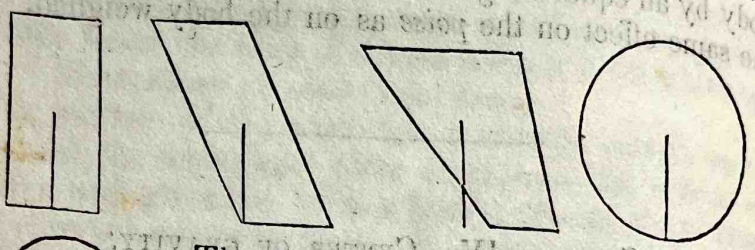
The nature of gravity is such as will make it alway

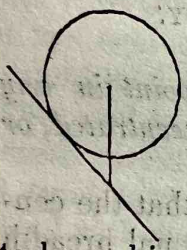
descend to the lowest possible point, and therefore, if any body is freely suspended, its center of gravity will fall directly under the point of suspension, or in the plumb line; and if we suspend it from two points, we shall find two lines in which the center of gravity must be situated. Therefore it must be at their point of intersection.

In this manner we may find the center of gravity of small irregular bodies, whose positions may be changed.

While the center of gravity of any body is supported, the body itself will retain its position, but if the center of gravity is not supported, does not rest on a base, the body will fall until that centre finds a base.

This will be sufficiently illustrated by the following figures.





The base, on which a man is supported in walking or standing, is his feet, and the space between them.

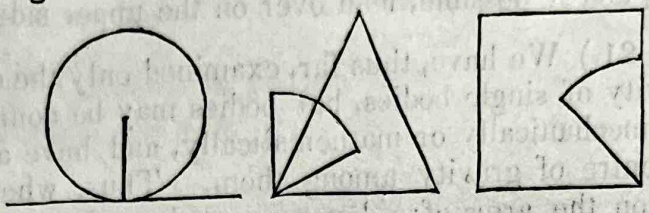
A man standing on one foot, cannot throw his body forward without at the same time throwing his other foot backward, in order to keep his center of gravity within the base.

A man, therefore, standing with his heels against a perpendicular wall, cannot stoop forward without falling, because the wall prevents his throwing any part of his body backward. A person, little versed in such things, agreed to pay a certain sum of money for an opportunity of possessing himself of double the sum, by taking it from the floor with his heels against the wall. The man, of course, lost his money, for in such a posture, one can hardly reach lower than his own knee.

Bodies are the most stable when the center of gravity is over the center of the base; and the wider the base and the lower the center of gravity, the more difficult it is to overturn the body.

A cube is more easily turned over than a pyramid of

equal base and altitude, notwithstanding the cube contains more matter than the pyramid; the center of gravity of the pyramid must be *lifted* higher than that of the cube, before its perpendicular leaves the base, as the following figures will illustrate.



A ball can be rolled along a horizontal plane with very little force, because the center of gravity has not to be raised. A ball, on an inclined plane, will roll down, because its center of gravity is not supported by a base.

Any body can be moved along (all other circumstances being equal) in proportion as the center of gravity can be kept in a uniform line. The center of gravity of a person is between the hips, and the easy and graceful walker will keep this point quite near a uniform line while walking; but the awkward and ungraceful walker will throw his center of gravity up and down, to the right and to the left, while walking, and it requires much more muscular strength for him to walk a given distance, than it would were he a more skilful and graceful walker.

Every one is aware of the great fatigue occasioned by walking over a plowed field, and the effort necessary to ascend a hill. In the former case we must lift the center of gravity of our bodies over the undulation of every furrow, and in the latter we must expend as much strength as is requisite to lift the weight of our bodies up the *perpendicular* ascent of the hill.

The art of rope-dancing, walking on a wire, and the thousand fetes of circus riders, is no more than skill and dexterity in keeping the center of gravity over the base.

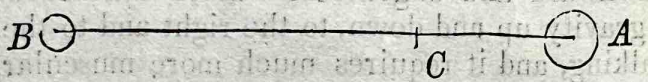
No form under which matter exists escapes this general law of gravity. Vegetables, in their growth, appear to have a sensitive care in this particular. Wheat, corn, and other stalks of grain grow perpendicular, for that is the only position that they can support the center of gravity without straining some of their fibres.

Trees and plants which have been made to lean, by any force or accident, afterwards grow so as to have the utmost tendency to preserve the center of gravity; the roots creep out in the opposite direction from which the tree leans, and the limbs from the under side turn up perpendicular, and if possible, lean over on the upper side.

(Art. 21.) We have, thus far, examined only the center of gravity of single bodies, but bodies may be connected either mechanically or mathematically, and have a common centre of gravity among them. Thus, when two bodies on the arms of a lever are balanced on a point called the *fulcrum*, that point is the common center of gravity between the two bodies, and the real principles of the *lever* are all embraced in the fundamental doctrines of *center of gravity* and *momentum*.

The doctrine of the center of gravity, is a *rest* on a point, and there cannot be a rest unless there are *equal forces* on opposite sides, but force in this sense is *momentum*.

Fig. 15.



Let A and B represent the mass of two bodies at a distance asunder. Conceive them connected together by a bar *devoid of weight*, and balanced on the point C, which point must be the common center of gravity between the two bodies A and B.

But if the bodies balance, the bearing down force of A, exerted at the point C, is equal to the bearing down force of B at the same point.

But these *bearing down forces* do not depend alone on the weight of the bodies, for their weights are not equal. These forces are *momenta*.

To understand this, conceive the bodies to have a slight motion on the center C, B *downwards* and A *upwards*, and the comparative distances which A and B will move, will be as their distances from the point C, therefore their comparative *momenta*, will be expressed by Art. 5. A multiplied into the distance CA, and B multiplied by the distance CB. Put $CA=x$ then $CB=a-x$.

Now if the point C is the center of gravity, we must have $Ax = Ba - Bx$

Therefore $x = \frac{Ba}{A+B}$.

That is, to find the distance of the centre of gravity from the larger of two bodies, we have the following

RULE. *Multiply the whole distance by the weight of the smaller body, and divide that product by the sum of the two bodies.*

EXAMPLES.

1. Two bodies whose weights are as 4 to 27, and are 20 feet asunder. Where is their common center of gravity between them? *Ans.* $2\frac{1}{3}\frac{3}{1}$ feet from the larger body.

2. The weight of two bodies are as $1\frac{2}{7}$ to $10\frac{1}{2}$, and their distance asunder is 31 feet. How far is the center of gravity from the larger body? *Ans.* $3\frac{2}{5}\frac{1}{5}$ feet.

3. The comparative weights of the moon and earth are as 1 to 75, and their distance asunder 60 times the radius of the earth; how far is their common center of gravity from the center of the earth?

Ans. $\frac{6}{7}\frac{0}{6}$ or $\frac{4}{5}$ of the radius of the earth from the center, or $\frac{1}{5}$ below the surface; that is near 800 miles below the surface.

This is the point round which both the earth and moon revolve during the moon's periodical revolution.

4. A body whose weight is 20, and 3 feet from a center; what number must represent the weight of another body on the other side to balance the first at a distance of 12 feet? *Ans.* 5.

(Art. 22.) The entire weight of bodies may be conceived as resting on the common center of gravity, and from this fact another view of this last example can be taken. We may suppose 25 pounds resting on an imponderable bar, 15 feet long, the weight 3 feet from one end, and two persons lifting at the ends of the bar, the one nearest to the weight must lift 20 pounds, the other must lift 5 pounds, and this establishes the following truth:

That when the weight of a body, or any number of bodies is at a point, the lifting or counteracting force must be reciprocal to the distance from that point.

On this principle we can resolve the following questions:

1. A stick of timber 30 feet long, of uniform breadth and thickness, is to be carried by three men, one at the end, the other two on a handspike near the other end. How far from the forward end shall they place the handspike that each man shall sustain one-third of the weight?

Ans. $7\frac{1}{2}$ feet.

Here we may suppose the entire weight of the stick collected at the center, and of course the two men must be only half as far from that point as the one man. Therefore they must be placed $\frac{1}{4}$ of the distance from one end.

2. A plank of uniform thickness and density, of triangular shape, 2 feet wide at one end, a point at the other, and 30 feet long, is to be carried by three men, one man at the extreme point, the other two with a handspike near the other end. How far from the large end must the two men be placed, so that each man shall carry an equal portion of the weight, the center of gravity of a triangle being $\frac{1}{3}$ of the distance from the base towards the vertix?

Ans. Just at the end.*

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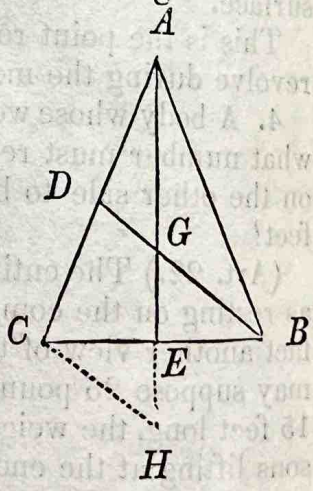
*Note. The center of gravity of a triangle is found in the following manner:

Fig. 16.



Let ABC represent any triangle; bisect the base BC in E, and join AE; also bisect AC in D, and join BD; the point G where these two lines intersect is the center of gravity required, and EG is one-third the distance EA.

Conceive the whole triangle composed of lines parallel to BC. The center of gravity of the line BC is at E, and the center of gravity of all lines parallel to BC will be in the line EA; therefore the center of gravity of the whole triangle is somewhere in the line EA. Reasoning in the same manner, we find the center of gravity of the triangle somewhere in the line DB, it is therefore at G.

Draw the dotted line CH parallel to DB, and produce

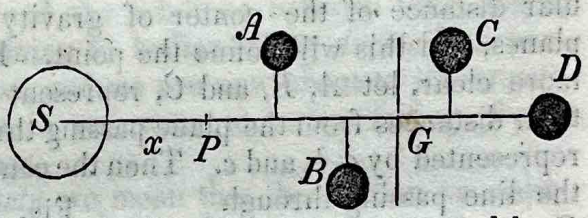
3. The center of gravity of a cone is $\frac{1}{4}$ of the distance from the base to the vertex. In what position then would you place three men, two with a handspike and one alone, that each one may carry one-third of the weight of a stick of timber one foot in diameter at one end, a point at the other, and 20 feet long?

Ans. The two men must be placed at the extremity of the large end, and the one man must be placed 15 feet from the same end, or 5 feet from the vertex.

(Art. 22.) To find the common center of gravity between several bodies, we proceed as follows:

We first consider that gravity acts in a perpendicular direction, and the center of gravity is that point on which all the bodies would balance.

Fig. 17.



Let PD be any horizontal line, and A, B, C, D, &c. any bodies, whose horizontal distances from any assumed point P taken at pleasure, are represented by a, b, c, d, &c. and G the point on the horizontal line PD where they would all balance, then the common center of gravity would be somewhere in the perpendicular line drawn through G.

Conceive the line PD produced from P in the direction opposite from D, and conceive also a body S equal in weight to the sum of all the weights A, B, C, D, &c. and at such a distance x from P, as will cause it to balance all the weights A, B, &c. on the point P.

Then we must have the equation

$$Sx=aA+bB+cC+dD, \text{ \&c.}$$

AE to H. Then the two triangles BEG and EHC are equal, for $BE=EC$, and by reason of the parallels, the angle EBG is equal to the angle ECH, and the vertical angles at E are equal; therefore, EH is equal to EG. And because CH and DG are parallel, and $AD=DC$, it follows that $AG=GH$. Therefore $EG=\frac{1}{4}AH$ or $EG=\frac{1}{3}AE$.

But as $S=A+B+C$, &c.

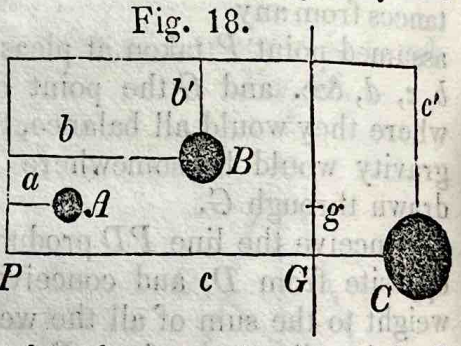
We have $x=\frac{aA+bB+cC+\text{ &c.}}{A+B+C+\text{ &c.}}$

Now from P take PG equal to x, and G will be the point on the horizontal line where all the bodies will balance. Therefore the common center of gravity between all the bodies, A, B, C, &c. is at the point G, or *directly above or below* that point.

If we conceive a perpendicular plane to pass through the point P, then the distance of the center of gravity from that plane, *or from any plane*, may be determined *by the sum of the momenta divided by the sum of all the weights.*

In the same manner we may determine the perpendicular distance of the center of gravity from two given planes, and this will define the point. But to render this more clear, let A, B, and C, represent three bodies and their distances from the plane passing through P, (Fig. 18) represented by a, b, and c. Then the centre of gravity is in the line passing through G, parallel to the plane passing through P.

Fig. 18.



Now conceive PG to represent a plane, and a', b', and c' the distances of A, B, and C, from that plane, and we find the center of gravity must be at the distance Gg from the plane passing through G, therefore it must be at the point g.

CHAPTER V.—GRAVITY DOWN INCLINED PLANES—PENDULUMS—FORCE OF GRAVITY ON MOUNTAINS—COMPENSATING PENDULUMS.

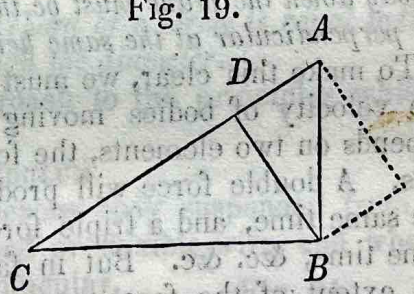
(Art. 23.) The subject of gravity, and the fall of bodies is the most fruitful and important of any in mathematical philosophy; and for this reason we enlarge upon it more than any previous author has done in any work of similar design. But in so doing, we are compelled to introduce the subject of *inclined planes* before we otherwise would; that is, before we treat in general on the subject of mechanical powers.

We have examined the relations between time, space, and velocity pertaining to bodies falling *freely* in a perpendicular direction, and we are now about to investigate the same relations in reference to bodies falling *freely* down *inclined* planes.

By the word *freely*, we mean that the friction or resistance of the plane *shall not* be taken into account.

Let AB (Fig. 19,) represent a perpendicular plane, or a perpendicular, BC a horizontal plane, and AC an *inclined plane*.

Fig. 19.



Draw BD perpendicular to AC, and AE parallel to BD, and BE parallel to AD.

By what precedes, it is supposed that the reader is acquainted with all the elements or circumstances of a body falling freely by the force of gravity down the perpendicular AB.

But the force which carries the body down the perpendicular AB, may be considered as the result of two forces, (Art. 15,) AD and AE. Forces which act precisely under the same laws of gravity as the perpendicular force AB, as we have supposed no *friction* on the planes AD and AE. But the force AE being perpendicular to AC,

is entirely destroyed by the plane, and *the time down AD must be equal to the time down AB.*

Hence the force down the inclined plane AC is to the force of gravity down AB as AD to AB, (or which is in the same proportions) as AB to AC.

Now let t represent the time down AD, (or which is the same as the time of falling freely down AB,) and x the whole time down AC.

Then by the laws of falling bodies we have the proportion, as $t : x :: \sqrt{AD} : \sqrt{AC}$.

But by proportional triangles, we have

$$AD : AB :: AB : AC.$$

From this we have

$$\sqrt{AD} = \frac{AB}{\sqrt{AC}}.$$

Substituting this value of $\sqrt{AD}$ in the first proportion, and multiplying the last couplet by $\sqrt{AC}$ we have

$$t : x :: AB : AC.$$

That is, the time down the perpendicular is to the time down the plane, as the height of the plane is to its length.

(Art. 24.) We now propose to show, that *the velocity of a body down the plane must be the same as the velocity down the perpendicular at the same height.*

To make this clear, we must call to mind the fact that the velocity of bodies moving by the force of gravity, depends on two elements, the force acting and the time it acts. A double force will produce a double velocity in the same time, and a triple force a triple velocity in the same time, &c. &c. But in falling bodies, whatever be the extent of the force, more or less, the velocity increases as the time, (Art. 7,) therefore the actual velocity of all falling bodies must be a compound of *force* and *time*.

Now let F represent the force down the perpendicular, and f the force down the plane AC.

Then, by Art. 23, we have

$f : F :: AB : AC$, and by the same Article we have $x : t :: AC : AB$.

By multiplying these proportions and reducing the last couplet, we have $fx : Ft :: 1 : 1$.

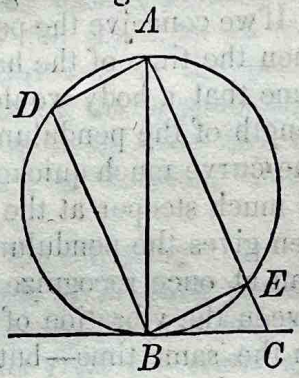
That is, the compound of the force and time down the plane, and the compound of the force and time down the perpendicular, *is a ratio of equality.*

But these compounds are only other terms for velocities, therefore the velocities are equal at equal heights.

Hence, we may conclude that the velocities acquired by bodies descending down different inclined planes from the same height to the same horizontal line, are equal. Hence, also, the velocities acquired by descending down any planes, are as the square roots of the heights.

(Art. 25.) Let *AB* represent any perpendicular, and make it a diameter to a circle. Then, by geometry, we know that all angles in a semi-circle, as *ADB*, are right angles, and *BD* is perpendicular to the plane *AD*, and by the first part of Art. 23, we know that the time down *AD* or *AE* is equal to the time down *AB*. But *BD* is equal in length and inclination to *AE*, therefore the time down *BD* is equal to the time down *AB*.

Fig. 20.



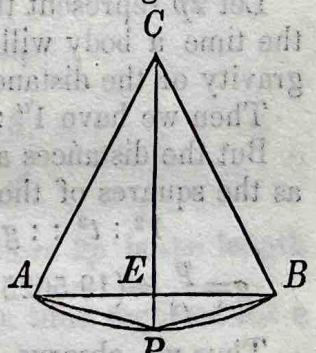
Hence, the time down any chord of a circle is equal to the time of falling freely through the diameter.

(Art. 26.) We now approach to the principles which govern the

PENDULUM.

A pendulum is any ponderous body suspended from a center of motion by a thread or flexible wire, and when drawn aside from the perpendicular, it will return to it by the force of gravity, and if that force were greater it would return quicker, or with a greater velocity.

Fig. 21.



Let *P* represent a pendulum, and *C* its point of suspension, and *A* the distance it is drawn aside. It will return along the curve line *AP*, and when it arrives at the lowest point *P*, it will have a velocity equal

to that of falling freely through EP, and that velocity (if it were not for friction and the resistance of the air) would carry it to B against the action of gravity; from thence it would return with nearly the same velocity as before, and thus continue to vibrate in the same time, but in a shorter and shorter arc, and would finally cease, unless maintained by some mechanical contrivance, as in clock-work, called a retaining power. Yet the pendulum itself is the *regulating power*, not the moving power of the clock.

As all bodies fall the same distance in the same time, so a pendulum of the same length will vibrate in the same time, whether its weight is one, or two, or ten pounds.

If we conceive the pendulum to pass down the chord AP, then the time of the half vibration (Art. 22,) would be the time that a body would require to fall through twice the length of the pendulum; but the pendulum will pass down the curve much quicker than down the chord, as the curve is much steeper at the first descent, which more of a sudden gives the pendulum a greater velocity, and the reader can at once recognize that some relation must exist between the vibration of a pendulum and the fall of a body in the same time—but the investigation of that theorem is too intricate for a work like this; we therefore only give the result, which is as follows:

The time of one vibration is to the time of falling through half the pendulum, as the circumference of any circle is to its diameter.

Now, observation has shown that a pendulum of $39\frac{1}{8}$ inches long will vibrate seconds—from which we can compute how far a body will fall in one second, by the following process:

Let $2p$ represent the length of the second pendulum, t the time a body will fall through p, and g the force of gravity or the distance a body will fall in one second.

Then we have $1'' : t :: 3.1416 : 1$ or $t = \frac{1}{3} \cdot \frac{1}{1}\frac{1}{4}\frac{1}{1}\frac{1}{6}$

But the distances a body will fall in different times are as the squares of those times; therefore

$$1^2 : t^2 :: g : p \quad \text{or}$$

$$g = \frac{p}{t^2} = (19.5625)(3.1416)^2 = 193,+ \text{ in. or } 16\tfrac{1}{12} \text{ feet.}$$

Thus we observe the distance a body will fall in one

second of time, we really observe the length of a pendulum which vibrates seconds, and from that we compute the fall of a body in one second, and call it *observation*; direct and accurate observations are impossible.

(Art. 27.) *By means of the pendulum we can ascertain the figure of the earth and measure the height of mountains.*

We have seen in the preceding articles that a pendulum vibrates by the force of gravity, and hence the vibration is the measure for gravity; but the terrestrial gravity is greatest at the level of the sea, and less as we ascend the mountain; it is also greatest at the poles, and less as we approach the equator. Hence, a pendulum of the *same length* will vibrate quicker, and make more vibrations in a day or an hour, on the level of the sea than on the mountain, and will make more vibrations at the poles than at the equator. It has been found that a pendulum which makes 86,400 vibrations in a mean solar day, at the equator, will, when transported to London, make 86,535 vibrations in the same time.

But to be more explicit, we state the following

Proposition. *The times of vibration of the same pendulum on different parts of the earth's surface, are proportional to the distance of these points from the center of attraction.**

If this proposition is true, and the radius of the earth

---

*Note. The force of the earth's attraction, considered as a sphere, is equal to the mass of the earth divided by the square of the radius. Now let R represent the radius of the earth, h the height of a mountain or other elevation, M the mass of the earth, g the force of gravity on the level of the sea, and g' the force of gravity on the mountain.

Then we shall have this proportion,

$$\frac{M}{R^2} : \frac{M}{(R+h)^2} :: g : g'$$

$$\text{Or} \quad (R+h)^2 : R^2 :: g : g'$$

But by the last equation $g = \frac{p}{t^2}$ where $2p$ is the length of the second pendulum, and t is the time required for a

SECTION II.

CHAPTER I.—MECHANICAL POWERS—LEVER—INCLINED PLANE—WEDGE—SCREW—PULLEYS, AND THEIR COMBINATIONS.

The mechanical *powers*, as here designated, refer only to the power or advantage gained by using particular instruments or machines, and does not refer to the *force* which may be used to put any machinery in motion, such as wind, water power, and steam power.

A single instrument, as a pin, an axe, a spade, &c. is a tool; and a combination of tools or instruments is called a machine—hence, tools are simple, and machines, as a general thing, complex.

Some authors give us *six* mechanical powers, but in their essential and elementary condition, we can find but *three*:—the *lever*, the *inclined plane*, and the *multiplied cord*. From the lever we have the wheel and axle, and from the inclined plane we have the wedge, and the *screw* is nothing but a winding inclined plane or winding wedge, and it is by this extension that some have made the six mechanical powers. But for greater perspicuity, we shall admit but three, and treat of them in the order here stated,—first,

THE LEVER.

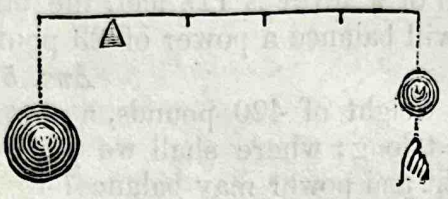
(Art. 29.) The lever, theoretically considered, is an inflexible bar, without weight, and when in use, rests on a point called a *fulcrum*, having the *resistance* or weight on the short arm, and the *power* on the long arm, and when the weight and power balance, the *fulcrum* is at the common center of gravity between these two bodies, and its position may be computed by the rules of finding center of gravity, explained in the last section.

Levers are of *three kinds*, distinguished by the position of the *fulcrum* and the moving *power*, with respect to each other.

In all cases, *the fulcrum is the immoveable point.* A

lever of the first kind has the *fulcrum* between the weight and the power.

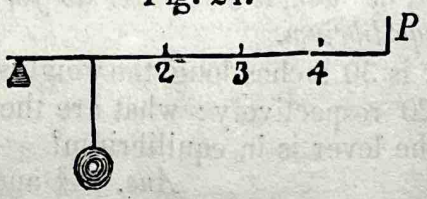
Fig. 23.



Of this kind, balances, scales, crows, handspikes, scissors, &c. are examples.

A lever of the second kind has the weight between the power and the fulcrum.

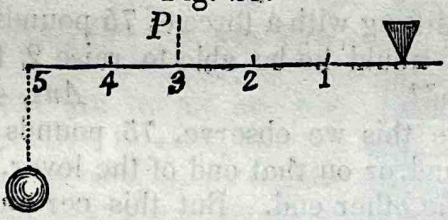
Fig. 24.



Oars, rudders, cutting-knives that are fixed at one end are examples.

A lever of the third kind has the power between the weight and the fulcrum.

Fig. 25.



Tongs, a man rearing a ladder, also the bones and muscles of animals, are examples of this kind.

All computations between the weight and power on all kinds of levers, are resolved on the principle of equal *momenta* already explained (Art. 5), and we give the following examples to familiarize the pupil with this important principle.

EXAMPLES.

1. A lever 16 feet long, the fulcrum 3 feet from one end, is in a state of equilibrium, holding a weight of 390 pounds; what is the power? *Ans.* 90 pounds.

2. The arms of a lever are, the one 20, the other 5 feet; what weight will a power of 60 pounds balance?

Ans. 400 pounds.

3. One arm of a lever is $11\frac{1}{2}$ feet, the other 6 inches, what weight will balance a power of 23 pounds?

Ans. 529 pounds.

4. Given a weight of 420 pounds, a power of 40, and a lever 18 feet long; where shall we place the fulcrum that the weight and power may balance?

Ans. $1\frac{13}{23}$ feet from one end.

N. B. This last problem is the same as the following:

5. Divide 18 into two such parts, that one may be to the other, as 420 is to 40, which is a problem in *fellowship. Indeed, the weight and power do form fellowship to preserve an equilibrium.*

6. A lever is 30 inches long, the weights at the two ends are 12 and 20 respectively; what are the lengths of the arms when the lever is in equilibrium?

Ans. $18\frac{3}{4}$ and $11\frac{1}{4}$ inches.

7. The difference in the lengths of the arms of a lever is 6 inches, the weight on one arm is 20 pounds, and the weight on the other is 30; the lever is in equilibrium; what is its length?

Ans. 30 inches.

8. A lever 12 feet long, one end resting firmly on a point, a man lifting with a force of 75 pounds at the other; what weight would he be able to raise 2 feet from the stationary end?

Ans. 450 pounds.

To analyze this we observe, 75 pounds must rest on the man's hand, or on that end of the lever, and a certain weight on the other end. But this certain weight must bear the same relation to 75 pounds as 2 feet to 10 feet.

Or, as 2 : 10 : : 75 : 375.

That is, 75 pounds on the man's hand, and 375 pounds on the fixed point, therefore the whole weight is 450 pounds.

9. A man capable of lifting 375 pounds, takes hold at the end of a lever 24 feet long; what weight can he raise 6 inches from the other end as a fixed point?

Ans. 18000 pounds.

When several weights are suspended on one side of a lever, at different distances from the fulcrum. To find

the momentum on that side, multiply each weight by its distance from the fulcrum, and add the several products together. We can then find what weight will balance this on the other side of the fulcrum by dividing by that arm of the lever.

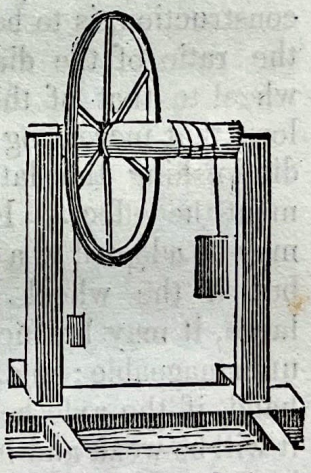
10. The two arms of a lever are 12 and 8 inches, respectively; 2 inches from the fulcrum on the short arm is suspended 20 pounds, at 6 inches is suspended 30 pounds, and at 8 inches is suspended 40 pounds; what weight o the extremity of the other arm will balance these?

Ans. 45 pounds.

11. A man weighing 150 pounds rests on the short arm of a lever $1\frac{1}{2}$ feet from the fulcrum, on the other side 20 pounds is suspended 5 feet from the fulcrum; there is another weight of 15 pounds; where must it be placed on the lever to make an equilibrium?

Ans. $8\frac{1}{3}$ feet from the fulcrum.

Fig. 26.



The *wheel* and *axle* is but a continuation of the lever, or a series of levers, filling up the whole circle round the fulcrum. The point or line on which the wheel turns is the fulcrum of the lever, the semi-diameter of the wheel is the long arm of the lever, the semi-diameter of the axle is the short arm; but circumferences are to one another as their respective semi-diameters; therefore we can compute for equilibrium between weight and power, on the wheel and axle, the same as we do on the long and short arms of a lever, considering the circumference or diameter of the wheel the long arm, and the circumference or diameter of the axle (according as which may be given), the short arm of a lever.

EXAMPLES.

1. If the diameter of the axle be 6 inches, and that of the wheel 6 feet; what weight attached to the axle, will balance 16 pounds attached to the wheel?

Ans. 192 pounds.

Solution—As $\frac{1}{2} : 6 :: 16 :$ Answer.

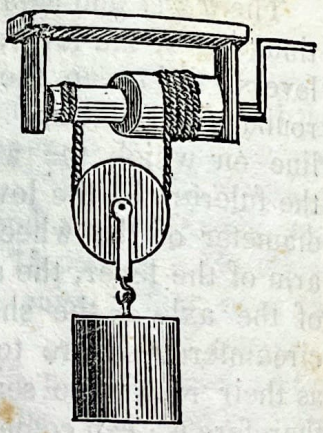
2. A large stone, supposed to weigh about 2 tons, or 2000 pounds, is required to be raised by a wheel and axle, the axle 2 feet 6 inches in circumference, and the circumference of the wheel 18 feet; what power must be applied to the wheel? *Ans.* $277\frac{7}{9}$ pounds.

N. B. The answer to the last question is on the supposition that the machine is perfect, and experiences *no friction;* but such can never be the case in practice: the power must always bear a greater proportion to the weight, some say $\frac{1}{3}$ more.

3. The diameter of a wheel is 12 feet, to which 60 pounds are applied, and balances 3600 on the axle; what is the diameter of the axle? *Ans.* 2,4 inches.

4. If the diameter of an axle be 2 feet, and the diameter of the wheel 20 feet, what power will balance a weight of 4000 pounds? *Ans.* 400 pounds.

Fig. 27.



As the efficacy of the wheel and axle, whatever may be its peculiar construction, is to be estimated by the ratio of the diameter of the wheel to that of the axle, it follows that increasing the former or diminishing the latter, will augment the effect. Either method may be adopted to a certain extent; but if the wheel be extremely large, it may be inconvenient and unmanageable; and, on the other hand, if the axle be very slender, it will be weak and insecure. Both these evils are avoided in the construction of the double axle, an ingenious contrivance, said to have been introduced from China. It consists of two cylinders, differing in diameter, connected as in the marginal figure, turning about the same axis, while the weight is suspended by the loop of a long cord, one end of which uncoils progressively from the smaller cylinder, as the other laps round the larger: thus the weight is elevated at each revolution through a space equal to half the difference between the circumferences of the two cylinders. But the weight multiplied by the distance through which it moves, is equal to the power multiplied

by the distance through which it moves; and on this general principle, we may compute the ratio between the weight and power when the circumference of the crank and the circumferences of the axles are given.

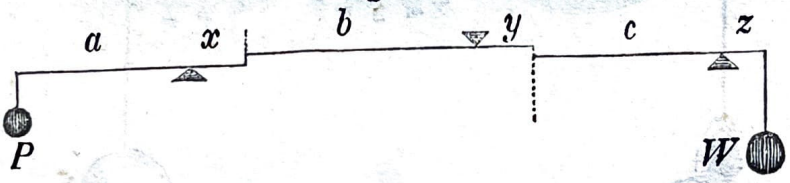
(Art. 30.) A combination of several levers, as in the adjoining figure, is called a

COMPOUND LEVER.

No additional principle over the simple lever enters into the compound lever. We estimate the momentum of the power at one end of the lever where it is placed, and divide it by the other arm of the simple lever, and the quotient is the *power* for the next lever, and so we may continue from lever to lever through the whole series; but more concisely, we have this

Proposition. *When the power and weight balance each other in the compound lever, the power multiplied into all the arm on the side next to it, is equal to the weight multiplied into all the arms on the side next to it.*

Fig. 28.



Commence at the power P, and the momentum of the extremity of the first lever will be $\frac{aP}{x}$. This is the power for the next lever, which gives $\frac{abP}{xy}$ for the power for the third lever.

Then $\frac{abcP}{xyz} = W$ or $abcP = xyzW$ an equation which proves the proposition.

EXAMPLES.

1. A compound lever consists of 5 simple levers, the shorter arms of each are 2 feet, the larger arms are each 8 feet, and the power is 20 pounds. What weight will balance it? *Ans.* 20480 pounds.

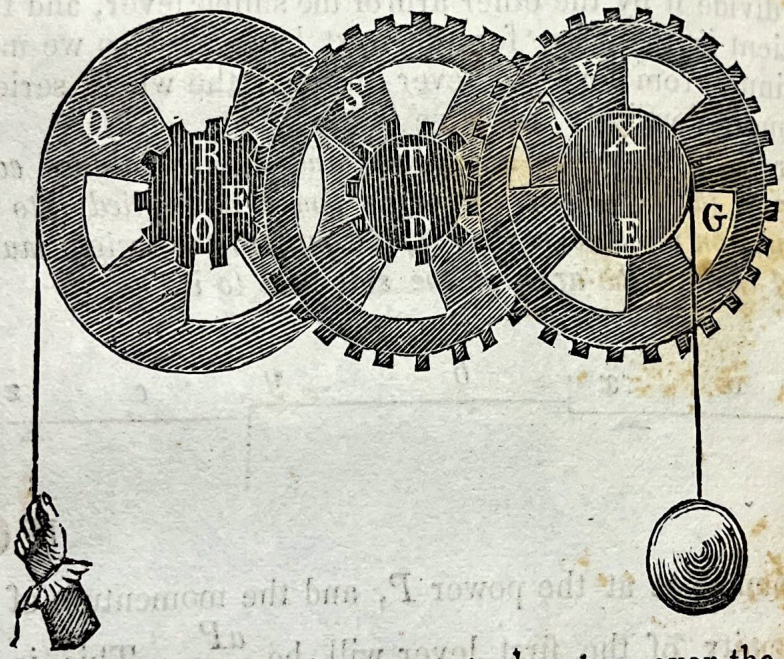
2. A compound lever consisting of 4 simple levers; the

ratio between the long and short arms of two of them is as 3 to 1. and the ratio between the long and short arms of the other two is as 9 to 4, and the weight is $2\frac{1}{2}$ tons, or 2500 pounds. What power will balance it?

Ans. 55 pounds nearly.

(Art. 31.) We have seen (Art. 29,) that the wheel and axle is but a perpetual simple lever; so several wheels and axles, as represented by the following cut, correspond to the compound lever.

Fig. 29.



The wheel and axle has a great advantage over the simple lever, in point of convenience. For a weight can be raised but a little way by the lever; whereas, by the continual turning of the wheel and roller, the weight may be raised to any height, or from any depth.

The same remarks apply to a series of wheels, with the additional advantage of having much more power in a smaller space than possibly could be with a single wheel and axle.

We have more than once reminded the reader, that the principle of *momenta* governs all these computations to find an equilibrium between the weight and power. We now add, that this is a universal principle in all mechanical philosophy, whatever may be the construction of the

machine, and it is recommended that the pupil commit to memory the following fact:

That the power multiplied by the distance through which it moves is equal to the weight multiplied by the distance through which it moves.

STEEL-YARDS.

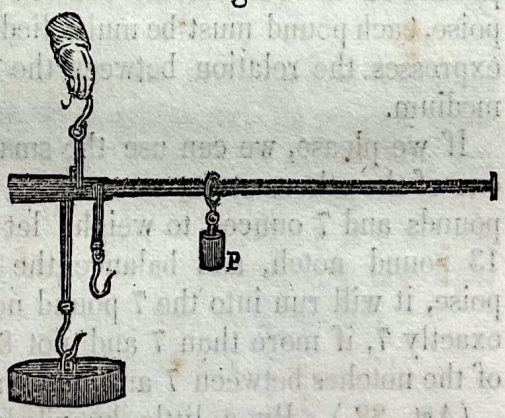
The steel-yard for weighing is but a lever of unequal arms, on which the same body called the poise, is made to balance different weights by placing it at different points along the long arm of the lever.

In an unimproved condition, there is no exact proportionality between the two arms—*no definite weight to the poise, and no definite distance between the hooks.* The accuracy of the instrument will depend entirely on the markings.

The blacksmith must draw out a bar of any convenient size and length, and put on hooks a short distance asunder. If two sides are used, one for the greater and one for the smaller weights, two hooks are to be put on, making two *fulcrums*, and there will be in fact two steel-yards with one bar and one poise.

To mark off a bar, we must have some definite weight, say 10 pounds. Hang that weight on the proper hook and slide the poise along on the (now smooth) bar until it exactly balances the weight, there file a notch, that must be the 10 pound notch.

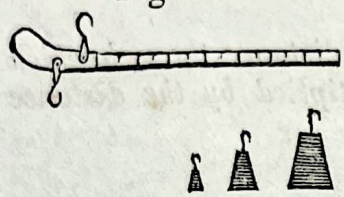
Fig. 30.



We can now weigh 10 pounds of any substance. Now hang on to the hook twice ten pounds, and slide the poise as before, and thus find the 20 pound notch. Divide the space between the 10 and 20 pound notches into ten equal parts, and one of these parts will be a pound division on the bar, with which it can be completely marked off, and all the desired subdivisions made.

The following improvement is made on the steel-yards,

Fig. 31.



known as the patent steel-yards. A brass bar is cast as represented by the adjoining cut, and by a little use of the file, the bar is made to balance before any markings are made.

The maker has adjusted a three-fold poise for this bar; *one very small*, another sixteen times its weight, and still another four, or five, or ten times the weight of the last, as may be proper or convenient for the size and strength of the bar. Now as the bar balances, if the medium poise weighs one pound, the one pound notch must be just as far from the *fulcrum*, or hook, as the two hooks are asunder. If the poise weighs less, the notch must be at a greater distance on the bar; if more, at a less distance; and by this inverse proportion the maker knows at once where the first pound notch must be, and the exact extent of a pound on the bar, and he adjusts a machine with which, at one or two turns, he cuts the entire divisions and subdivisions on the bar.

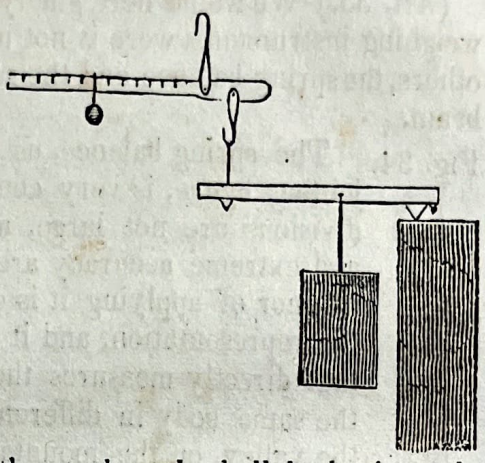
With these steel-yards, if we use the smaller poise, the pounds on the bar become *ounces*:—if we use the larger poise, each pound must be multiplied by the number which expresses the relation between the greater poise and the medium.

If we please, we can use the smaller poise with either one of the others at the same time. Suppose we have 13 pounds and 7 ounces to weigh: let one poise rest in the 13 pound notch, and balance the bar with the smaller poise, it will run into the 7 pound notch, if the ounces are exactly 7, if more than 7 and not 8, it will rest in some of the notches between 7 and 8 pounds.

(Art. 32.) By a little knowledge of the mechanical powers and a little mechanical ingenuity, we may weigh large weights with very small steel-yards,—and frequently the men on our western frontier have found it convenient to weigh a quarter of beef, a live animal, or a bale of hay by a pair of common steel-yards, which may be accomplished thus:

Take a strong even bar, sufficiently straight and inflexible, and divide it into any number of equal parts, say six.

Fig. 32.



Rest one end on a firm point as represented in the figure, and suspend the body to be weighed at one division from the fixed point, and let the other end of the bar rest on the hook of the steel-yards. Adjust the whole, by means of the poise, so that both the temporary bar and bar of the steel-yards shall be horizontal.

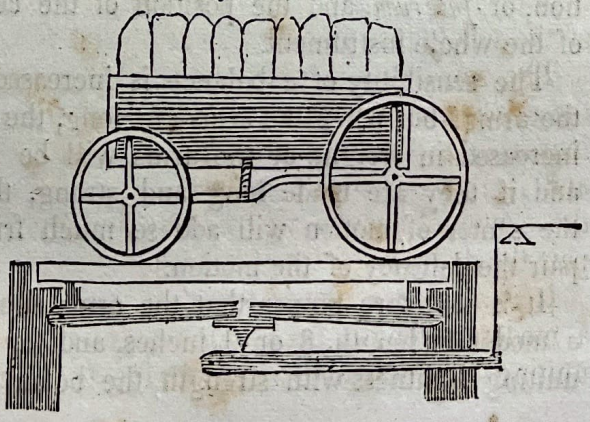
The weight indicated by the steel-yards is to be multiplied by 6, on the supposition that the body weighed was five divisions from the hook of the steel-yards and one from the fixed point, and so on for any other divisional arrangement that we may please to make.

To be accurate, one-half of the weight of the bar must be subtracted from the weight indicated, *before we multiply.*

The reader will at once perceive that this is the principle of the compound lever; and this is the principle of all the *patent scales* now in use.

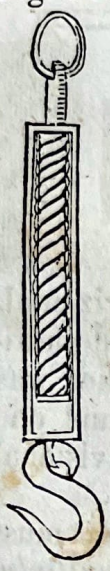
It is unnecessary, therefore, for us to go into a minute explanation of one of these instruments; its general principle is well understood, and the different kinds differ but little, except their style of construction and the minuteness and range of the scale beam. We deem it sufficient to give the following figure of a large weighing machine, such as is used for loads of hay, cotton, iron, &c.

Fig. 33.



(Art. 33.) We would here gladly dismiss the subject of weighing instruments, were it not necessary to notice two others, the spring balance and the recently improved scale beam.

Fig. 34.



The spring balance, as represented in the adjoining figure, is very convenient when the subdivisions are not large, and where minuteness and extreme accuracy are not attempted. The manner of applying it is easily understood from the representation, and it is the only instrument that directly measures the varying pressure of the same body in different localities, such as in the valley, on the mountain, at the equator, and at the pole.

After continued use with heavy weights, the elasticity of the spring is in a measure impaired, and the accuracy of the instrument diminished; but with common and careful usage, *spring steelyards* retain their accuracy for a long time.

The necessity of arriving at the weight of bodies, in delicate philosophical researches, and in chemical analysis, has induced men of science and artists, to bestow special attention to the construction of a *scale beam* or *balance* that would show *sensibility* to the least variation of weight and they have in a great measure succeeded.

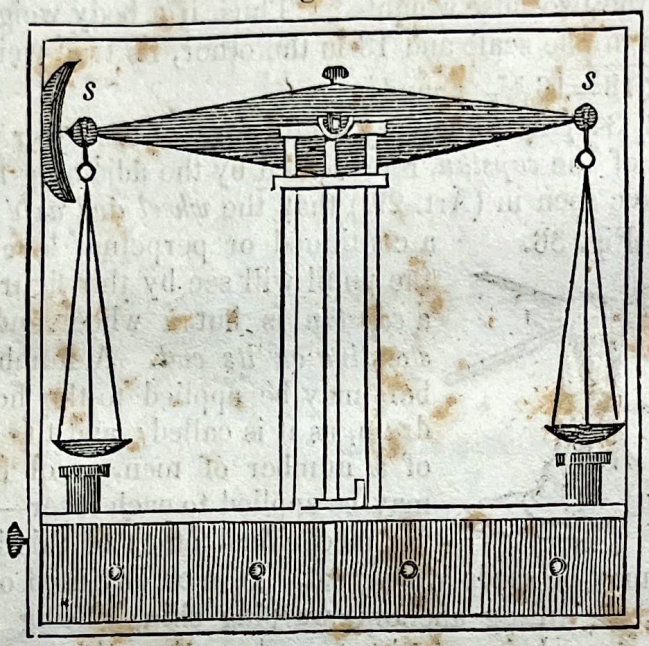
To construct a perfect balance, the particulars to be attended to, are the length of the arms, that is, the beam itself—the hardness and delicacy of the points of suspension at the extremity of the arms—the center of motion, or *fulcrum*, and the position of the center of gravity of the whole instrument.

The sensibility of a balance is increased by increasing the arms; but when the arms are long, the beam must be increased in weight, or the arms will be liable to bend; and if they are made long and strong, their weight on the center of motion will add so much friction as to impair the delicacy of the motion.

It is therefore proper that the arms should be only of a moderate length, 8 or 9 inches, and for the purpose of uniting lightness with strength, the beam is composed of

two hollow cones, placed base to base, as represented in the following figure.

Fig. 35.



The points of suspension, *s s* should be in the same line with the fulcrum or center of motion, and the center of gravity of the whole must be a little, *and but a little*, below the center of motion; for if the center of gravity were at the center of motion, a balance of weights would balance in all positions of the beam, whereas a balance is only desired in a horizontal position. If the center of gravity were far below the center of motion, the beam would be too stable, and consequently not sufficiently sensitive.

Fraudulent dealers may sometimes have a *false balance;* that is, one arm a little longer than the other, and the defect covered up by having the shorter arm or scale a little the heavier, that they may balance when empty: but when they are balanced with weights, those weights will not be equal.

The dealer turns such an instrument to his advantage both in buying and selling. Whatever he buys he puts on the long arm, for it will take more than its equivalent to balance it on the other; whatever he sells is put in the other scale. Hence, this fraud can be detected by

changing the body weighed from one scale to the other, and see whether it weighs the same in both scales. If it does not, *its true weight* is the mean proportional between the two false weights.* Thus, if a body weighs 16 pounds in one scale and 18 in the other, its true weight is $\sqrt{16\times18}=16\frac{97}{100}$ pounds.

(Art. 34.) Another very useful form of the lever power is that of the *capstan*, represented by the adjoining figure. We have seen in (Art. 29,) that the *wheel and axle* is but a continued or perpetual lever, and the pupil will see by this figure that a *capstan* is but a wheel and axle *standing on its end.* A number of bars may be applied to the head or drum, as it is called; and the power of a number of men, or of horses, may be applied to each lever—hence the mechanical effect of this instrument may be made very great. It is chiefly used on ship board, for lifting anchors, warping ship, raising heavy yards, &c. It is sometimes used on shore in connection with pulleys, for moving heavy buildings, and other kindred objects.

Fig. 36.

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* Note. This is investigated in the following manner: Let x represent one arm of the balance and y the other. Also, suppose a body weighs W pounds in one scale and w in the other, and a its true weight. Then by the principle of *momenta*,

We shall have $ax=Wy$,

and $ay=wx$.

By multiplying these equations together, and dividing each member of the new equation by xy, we have $a^2=Ww$ or $a=\sqrt{Ww}$.

That is, a the true weight, is a mean proportional between W and w.

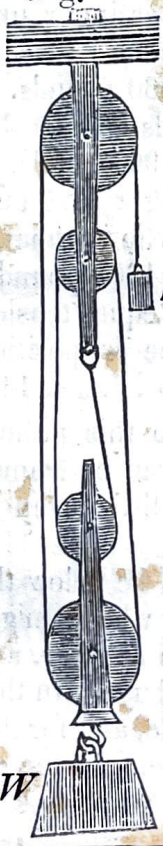
CHAPTER II.—THE PULLEY—THE MULTIPLIED CORD—THE INCLINED PLANE—SCREW—FRICTION—THE COMBINATION OF MECHANICAL POWERS.

(Art. 35.) The *pulley* is a single wheel, moveable on its center, with a cord running over it. A single pulley may be considered a perpetual lever, with the fulcrum in the center, or the two arms equal; and, of course, the weight and power must be equal, to produce an equilibrium. Hence, no power is gained by a rope running over a single wheel.

Fig. 37.

When a rope runs round a series of pulleys, it forms a

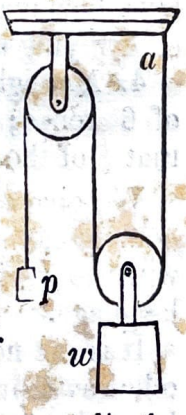
Fig. 39.



MULTIPLIED CORD.*

The principle of a single pulley, as we have just seen, can be resolved into the lever; but when any combination of wheels are made, it will facilitate our understanding of the subject to admit a new principle, or rather a new mechanical power, called the multiplied cord.

Fig. 38.



(Art. 36.) In the single *moveable* pulley, (Fig. 38,) the same rope passes from the fixed point *a*, to the power *p*. It is evident, here, that the weight is supported equally by the two parts of the cord between which it hangs. Therefore, if we call the weight *w* ten pounds, five pounds will be supported by one cord and five by the other. The power, then, will support twice its own weight, so that a person

* A machine of oblique action, to be described hereafter, is also called a MULTIPLIED CORD, but we can perceive no propriety in the name.

pulling with a force of five pounds at *p*, will raise ten pounds at *w*.

When a rope runs round a series of wheels, as in Fig. 39, called a system of pulleys, it is manifest that the weight should be equally divided among the ropes. As the whole machine is supposed to be free, the wheels can turn, and the tension of the rope can adjust itself; therefore, there is no reason why one portion of the perpendicular line of rope should bear more of the weight than another.

Hence, to find the power, *Divide the weight by the number of lines of rope sustaining it. Inversely, multiply the power by the number of ropes to obtain the weight.*

N. B. Care must be taken not to count the line of rope supporting the power *P*.

EXAMPLES.

1. A weight of 2240 pounds is sustained by four ropes, or which is the same thing, by one rope passing round four pulleys; what power is required to balance it?

Ans. 560 pounds.

2. What weight will a power of 15 pounds balance by running round six pulleys? *Ans.* 90 pounds.

3. By the aid of 12 folds of cord running round pulleys, how many pounds will a man sustain who is capable of applying a power of 150 pounds? *Ans.* 1800 pounds.

4. A weight of 560 is to be raised by the equal tension of 6 ropes; what power is required, on the supposition that $\frac{1}{3}$ of the power applied is lost by friction? *Ans.* 140.

We give very few examples applicable to this pulley, as they can present no difficulty, and they can be framed with no variation of principle, and very little even in language.

It is not necessary that one wheel should be below the other as represented in the figure, the upper wheels might be set in one block, and the lower wheels in another, and indeed, this is their construction for practical use. In that shape they are more convenient and portable, and for this reason, that is the shape in which we see them for every-day practical use, in warehouses and on board of vessels.

We represent it as in Fig. 39, for the sake of perspicuity only.

If the moveable pulleys are constructed and arranged as in Fig. 40, it is plain, by inspection, that the first moveable pulley doubles the power, that result is doubled by the next moveable pulley, and so on. Hence, if there are four moveable pulleys, as represented in the figure, the weight must be 16 times the power to make an equilibrium.

Observe that each moveable pulley gives a power to the number 2. Here are 4 pulleys, and we have $2^4=16$ for the multiplier to the power, whatever it may be. If we had 10 moveable pulleys in the series, the ratio between the weight and power would then be 2^{10} or 1024.

Fig. 40.

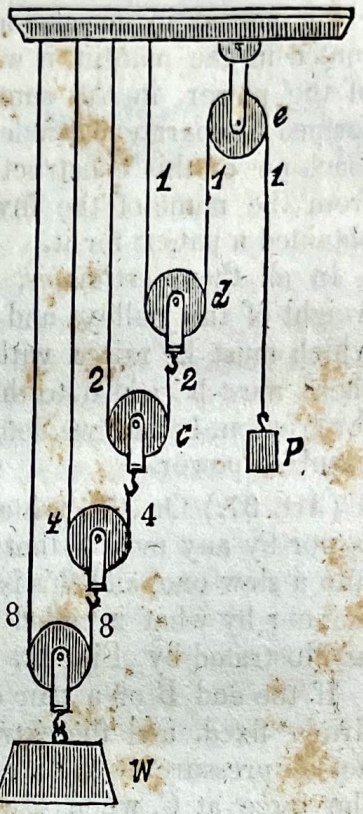


Fig. 41.

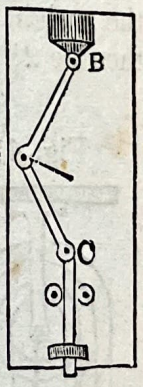
A great variety of systems, or as they are commonly termed, tackles of pulleys, have been contrived; but the advantages they respectively afford may always be estimated by reference to the spaces relatively described by the power and the weight. The greatest inconvenience occurring in the practical application of the pulley, is owing to friction, and consequent irregularity of action. Various plans have been adopted to remedy this defect; one of the most ingenious of which consists in cutting a proper number of concentric grooves on the face of a solid wheel, with diameters, as the odd numbers, 1, 3, 5, &c. for the lower block, and corresponding grooves on another such wheel, with diameters, as the even

numbers, 2, 4, 6, &c. for the upper block. Then the cord being passed in succession over the grooves, as represented in the margin, it will be thrown off by the action of the power, in the same manner as if every groove formed a separate and independently revolving wheel. A machine of this construction is called White's pulley, from the name of the inventor, Mr. James White, who obtained a patent for it.

In all these estimates, no allowance is made for the weight of the pulleys and other parts of the machinery, which must be raised with the weight. The amount of these must be added to the weight, and allowance made for friction, before we determine the real amount of the required power.

(Art. 37.) On the principle of momenta, we can gain power by any method that we can convert a rapid motion into a slow one, and this is accomplished in a very simple manner by what is called the principle of *oblique action*, as illustrated by Fig. 42.

Fig. 42.



If the end *B* of a pair of jointed rods be firmly fixed, and the extremity *C* made to act by pressure, as by a man pushing at *A*, the force at *C*, when the bars are brought nearly into a straight line, may be equal to the weight of many tons.

On this principle is the action of our modern printing presses, and it has been adopted with great advantage, in several operations of art, where great momentary force is requisite to produce a given effect.

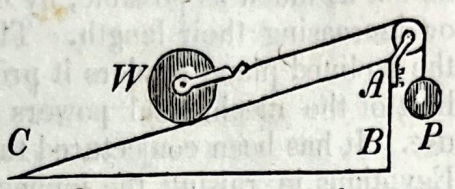
THE INCLINED PLANE.

(Art. 38.) We have already given a definition of the inclined plane in Art. 23, and have there explained the fall of bodies down its surface. The force of gravity is partially destroyed by the plane, and the portion not destroyed, is alone to be sustained by the acting power.

Of all the various directions of drawing bodies up an inclined plane, the most efficacious is that parallel to the plane, passing through the center of gravity of the weight, a direction which can easily be given it by fixing a pulley

at the vertex, as represented in Fig. 43. If the power were more horizontal, part of it would be destroyed by pressing upon the plane; if it were more elevated, part of it would be employed in lifting the weight and taking away in part the mechanical advantage of the plane. If the length *AC* of the plane be equal to any number of times its perpendicular height *AB*, as suppose 3 times; then a power *P* of 1 pound hanging freely, will balance a weight *W* of 3 pounds, laid on the plane: and a power *P* of 2 pounds, will balance a weight *W* of 6 pounds, and so on, always 3 times as much. But then if they be set in motion, the perpendicular descent of the power *P* will be equal to 3 times as much as the perpendicular ascent of the weight *W*. For, though the weight *W* ascends up the direction of the oblique plane *AC*, just as fast as the power *P* descends perpendicularly, yet the weight rises only the perpendicular height *AB*, while it ascends up the whole length of the plane *AC*, which is 3 times as much: that is, for every foot of the perpendicular rise of the weight *W*, the power *P* descends 3 feet.

Fig. 43.



In these theoretical considerations we suppose no *friction*, and therefore the power is supposed equal to that portion of gravity unsustained by the plane; but here the principle of equal momenta holds good, *for the weight multiplied by the distance it ascends in a perpendicular direction is equal to the power multiplied by the perpendicular distance of its motion.*

To find the power of an inclined plane, *Divide its length by its height.* If the power acts along the horizontal base, then *divide the base by the height.*

The simplest application of the inclined plane is that of raising one end of a plank to roll a barrel into a wagon. The force required to raise the body, thus gradually, is much less than would be required to lift it at once; and as we have explained, it is as the height of the plane to its length, but the time employed must be as much longer as the advantage of the plane is greater.

Every hill in the common highway is but an irregular

inclined plane. On rail-roads they are made more regular, and great attention is paid to diminishing their inclination as much as possible, by cutting down their height, or increasing their length. The very simple nature of the inclined plane renders it probable that it was the earliest of the mechanical powers known and brought into use. It has been conjectured that it was employed by the Egyptians in raising the immense blocks of stone which form the pyramids, and in executing other gigantic works, which have excited the astonishment of successive ages.

(Art. 39.) We have seen in Art. 23, that the motion of bodies falling down inclined planes is subject to the same law of gravity as bodies falling freely; that is, their velocities increased as the time, and the distances increased as the square of the time; and were it not for being retarded in a measure by friction, bodies, such as rail-road cars, would move with immense velocity when suffered to run unchecked, down inclined planes of any considerable elevation.

"A very remarkable example of the acceleration of bodies descending down inclined planes, occurs at the *slide of Alpnach*, in Switzerland. On a mountain near lake Luzerne, is a very valuable growth of fir trees, which on account of their inaccessible locality, remained for ages untouched, until within a few years a German engineer constructed a trough in the form of an inclined plane, in which the heavy logs are made to descend by their own weight, through a space of eight or nine miles.

"Although the average declivity is only one foot in seventeen, and the route often circuitous, and sometimes horizontal, yet so great was the first declivity, and so great was the acceleration, that the whole distance was passed over in little more than six minutes."

To familiarize the student with the principles of the inclined plane, we submit the following

EXAMPLES.

1. On a rail-road, one of the inclined planes rises at the rate of 30 feet to the mile; what portion of the train makes a dead weight? *Ans.* $\frac{30}{5280} = \frac{1}{176}$.

That is, 1 ton in every 176 tons.

2. Suppose the plane designated, as in last problem, to

be three miles in length, and cars run down it, without friction, and merely by the force of gravity; what velocity would they acquire, at the foot of the plane, and what would be the time of running, starting from rest at the top of the plane?

Ans. If we take the force of gravity at 16 feet, the cars would acquire a velocity of $24\sqrt{10}.=76$ feet nearly, in one second, which is at the rate of nearly 52 miles per hour—the time of running, 6 minutes 57 seconds. But on account of friction and the resistance of the air, there would really be no such result.

3. The elevation of a hill on a certain road, is 2 feet in 23; what portion of every wagon, with its load, is a dead weight, in passing up the ascent? *Ans.* $\frac{2}{23}$.

From the inclined plane we explain the

WEDGE.

(Art. 40.) The *wedge* is formed by two equal inclined planes put together. Its power is governed by the same principles as those of the inclined plane. The power applied to the head or end, is to the power on the side, as the *width* of the wedge to its *length*. But we cannot numerically measure the force of a blow; therefore, there is no object in giving problems under this head. It appears from the results of some experiments made in the Dock-yard at Portsmouth, on the comparative effect of driving and pressing in large iron and copper bolts, that a man of medium strength, striking with a maul weighing eighteen pounds, and having a handle forty-four inches in length, could start or drive a bolt about one-eighth of an inch at each blow; and that it required the direct pressure of 107 tons to press the same bolt through that space, but it was found that a small additional weight would press the bolt completely home. But numerous and varied experiments would be requisite to obtain any result which might afford data for computing the effect of impact or percussion on wedge-shaped bodies; and if that effect could be exactly estimated, farther difficulties would arise, from considering the very heterogeneous nature of the resistance,

Fig. 44.

depending on the relative hardness, tenacity, and other properties of those substances on which the wedge is made to act.

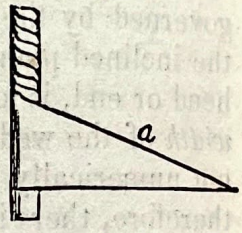
To sum up all, we find the wedge has great advantages over all other powers where it can be applied, such as splitting blocks of wood or stone, the raising of heavy bodies, such as a large ship in a dock, or restoring a leaning building to its perpendicular position, by driving wedges under one side, &c.

Sharp-edged and pointed instruments in general, act as wedges; thus, chisels, planes, and axes, used by carpenters, manifestly produce the effect of wedges; and knives, razors, awls, pins, and needles, and indeed all cutting and piercing instruments, display an obvious analogy to the common forms of this mechanical power.

THE SCREW.

(Art. 41.) Some persons define the screw as a *winding wedge*, acted upon by a lever power in place of percussion.

Fig. 45.



Perhaps it may be more clear to conceive the *screw* as an inclined plane wound round a shaft, as represented in Fig. 45. One turn of the screw gives us the comparative length of the plane, and the distance between the consecutive threads gives us the comparative height of the plane.

Therefore, to find the advantage of a screw (independent of the lever power applied to it,) *divide the winding circumference of the screw, by the* PERPENDICULAR *distance between the threads.*

But practically speaking, it is useless to consider the power of the *screw itself* as we consider the power of the inclined plane, as it would be found almost wholly ineffective without the aid of the lever power, with which it is usually combined, and thus becomes a most powerful machine, applicable to a great variety of purposes.

The lever may be added to the solid screw to turn it within a fixed hollow screw; or to the hollow screw, to turn it round the solid screw. The manner in which the lever is applied in either case, will appear from the

following figures. Fig. 46, shows how pressure may

Fig. 46.

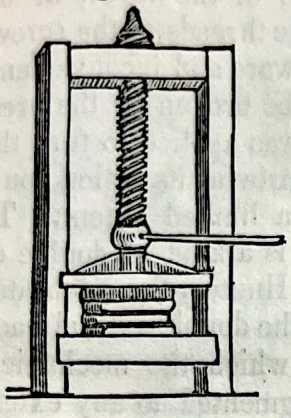
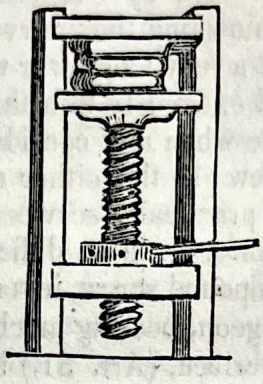


Fig. 47.



be produced by a solid screw acting within a hollow screw in a fixed beam; and (Fig. 47,) exhibits the similar effect of a hollow screw pierced in a block turning by means of a lever, on a fixed screw; the pierced block thus adapted to a solid screw is called a nut.

For a clear understanding of this machine, consider the power applied at the end of a lever, and pushed round one circumference, the screw in the same time will be passed through the distance between two consecutive threads. Then, (setting aside friction,) the principle of equal momenta will give the following rule for computation between weight and power:

RULE. *The power, multiplied by the circumference of its motion, is equal to the weight multiplied by the distance between the threads.*

EXAMPLES.

1. If the threads of a screw be 2 inches apart, the lever 40 inches in length, and a power of 60 pounds be applied to the end of the lever; what force is exerted by the screw?

Ans. 7540 pounds nearly.

2. Suppose the length of the lever to be 40 inches, the distance of the threads 1 inch, and the weight to be raised 8000 pounds; required the power?

Ans. $31\frac{1}{2}$ pounds nearly.

3. If the distance between the threads of a screw be 1 inch, and the lever 4 feet long, what weight could be sustained by a power of 350 pounds acting on the extremity of the lever? *Ans.* 105556 pounds nearly.

(Art. 42.) The efficacy of the screw may be indefinitely increased by extending the length of the lever, or by diminishing the interval between the threads of the screw. But a very long lever would be awkward and inconvenient, and extremely thin threads would be broken by the pressure when any considerable force was applied to turn the screw; so that either method of improving its action could be practically serviceable only to a limited extent. To counteract these difficulties, there is a kind of double or compound screw, invented by John Hunter, the celebrated surgeon, bearing much analogy to the double axle, already described, (Art. 31,) by means of which the mechanical efficacy of the machine may be augmented to any extent without diminishing its strength or compactness.

Fig. 48.

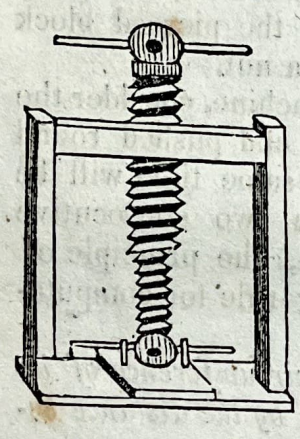


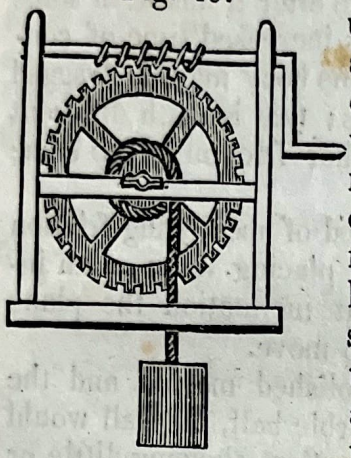
Fig. 48, represents how this may be effected. The screw consists of two parts, a greater and a smaller thread, one turning upon the other. The smaller thread is fixed firmly to the lower beam, and moves with it. The large screw is concave, and turns on and takes up the smaller screw, but it is so constructed as not to take up the smaller screw quite as much as the larger screw advances; so that, on the whole, the moveable beam will advance but with an extremely slow motion.

Suppose the upper and larger screw to have 10 turns of its thread in an inch, and the lower and smaller screw 11 turns. Then one turn of the screw would advance $\frac{1}{10}$ of an inch; therefore the moveable beam would advance $\frac{1}{10} - \frac{1}{11} = \frac{1}{110}$ part of an inch. That is, the power of such a screw will be the same as a simple screw having 110 turns of its thread in an inch. But a simple screw having so fine a thread, could bear but little application of force.

(Art. 43.) Screws are used for a great variety of purposes, and in a great variety of forms. When the thread of a screw is attached to a revolving axis, to act against the cogs of a wheel, as represented in Fig. 49, it is

called a perpetual screw, because it is in perpetual adjustment.

Fig. 49.



When slow, regular, and gradual motion is required, it can be attained and measured by means of a screw. Thus, suppose the wheel, as in Fig. 49, to be very nicely graduated, and the thread of the screw very regular and fine, we could decide how far, or how many degrees one turn of the screw would give the wheel, and then, of course, we know how far any portion of a *turn* would move it, and in no way could we move it so regularly, so slowly, or to such precision, as by the screw. Without entering into particulars, (which would require too much space,) we merely remark that this is the principle on which *tangent screws* and *micrometer screws* are attached to mathematical and astronomical instruments.

FRICTION.

(Art. 44.) We have several times, incidentally and of necessity, mentioned *friction*, taking it for granted that every one knew what it was,—*the adhesion or resistance which one body receives or meets with when moving on the surface of another.*

Friction between any two bodies may be measured by placing one body on the horizontal surface of the other, and observing what weight must be attached to it, hanging perpendicular over the edge of the plane, the cord between the body and the weight running parallel to the plane, and passing over a pulley at the edge of the plane. The weight necessary to attach to the cord that will just serve to drag the body along will be the measure of friction.

By this arrangement a great variety of experiments may be made, and many particulars concerning friction may be ascertained. For instance, a body shaped like a brick, with a broader and narrower side, may be tried on each side separately, to see what difference *extent of surface of contact* makes.

Different weights may be put on the sliding body, and thus determine the *influence of pressure* on friction.

The experiment may be made as soon as one body is placed on the other, and also made after it has been some time in contact, to learn whether increased time of contact increases friction. Finally, the body may be dragged off the plane by different weights; that is, with different velocities, and thus decided whether friction is the same for all velocities.

Perhaps a more accurate method of measuring friction (though not quite so simple) is by placing them on an inclined plane, and observing what inclination the plane must be, before the bodies *begin* to move.

If the inclined plane were polished marble, and the body placed upon it a smooth marble ball, the ball would begin to roll with the *least inclination*, showing little or no friction. Some writers have given us two kinds of friction, *sliding* friction and *rolling* friction; and the latter, as every one knows, is much less than the former, and for this reason, heavy bodies are moved on *rollers* in place of being dragged forward on the ground.

From varied and multiplied experiments on friction, the following facts are regarded as established:

1st. *Extent of surface* makes no difference in regard to friction, a body sliding on its edge or on its broad surface, requires the same power.

2d. Friction is in proportion to pressure, or weight, all other circumstances being equal.

3d. Friction is increased by bodies remaining in contact with each other. In some cases the maximum is not attained under four or five days. In the mutual contact of some metals, friction attains its maximum almost instantly; perhaps by the aid of a galvanic influence.

4th. Friction is less between surfaces of *different* kinds of matter than between those of the *same* kind. Cast steel is said to be an exception to this rule, and as this substance is alone capable of being *magnetized*, it has been suggested that magnetism might be the primary cause of the exception.

5th. Friction is much greater at the first moving of a load than after it is brought freely into motion.

In very slow motions, friction is increased; in rapid motions, it is diminished: and this fact is in favor of rapid travelling, and, accordingly, it is said, that the great speed given to stage coaches in England, of ten and twelve miles per hour, has not been attended with that degree of exhaustion to the teams that was anticipated.

For a more concise arithmetical result, we note

Friction for a sliding body, at ¼ the pressure, or 25 per cent.

For a revolving body, 15 per cent.

For a rolling body, 5 per cent.

Various methods and contrivances have been resorted to, to diminish friction, such as hardening, smoothing, and lubricating the rubbing surfaces. With these common methods, we may as well mention *friction wheels*, a theoretical contrivance to keep the axle of the wheel from rubbing against the fixed surface of the hollow cylinder, by having the hub filled at its extremities by small wheels, and in the circumference of these small wheels the axis of the large wheel rests, throwing the friction on the axes of the smaller wheels. Friction wheels are not much used in practice, as the first cost and the trouble of keeping them in repair more than counterbalances the advantage for all ordinary purposes.

Though friction, from its effect in retarding motion, lessens the advantage derived from machinery, and often causes inconvenience, yet it is one of those properties of matter which we find to be of almost indispensable utility. If all bodies were destitute of friction, it would be very difficult for us to grasp or retain in our hands any solid substance; a penknife, a ruler, or a book would slip through our fingers, if not held tightly; and, in using our hands for any purpose, such a degree of muscular power must be exerted as would be extremely fatiguing and inconvenient. But, without friction, it would be still more difficult to use our feet than our hands; and no man could walk upright unless he possessed the skill and activity of a tight-rope dancer, or a performer on the slack wire. The consequence of losing the advantage derived from friction in walking may be easily conceived, when we reflect on what takes place when friction is par-

tially destroyed, by the streets and open pavements being covered with ice, as occasionally happens during the winter season. Arming the soles of the shoes with list, or with projecting nails, and covering the ice with saw-dust, ashes, or other loose substances, are among the usual methods resorted to at such times, to restore friction and enable people to walk steadily.

Friction is advantageously used as a means of sharpening or polishing various substances, by rubbing, grinding, and other operations of great importance in several arts and manufactures. This property of matter may even be applied to the production of motion; at least, it may be made the medium of communication between one part of a machine and another. Thus, wheels are sometimes covered on their peripheries with buff-leather, and one of them being set in motion will then turn the other, by the friction of the rough surfaces of the leather, acting as if the wheels had been furnished with innumerable series of minute teeth.

Without friction, both the wedge and the screw would be useless machines, as neither could retain their position; nails would not hold boards together; and, when all things are considered, friction is by no means an evil in the philosophical world.*

COMBINATION OF MECHANICAL POWERS.

(Art. 45.) It is clearly obvious, that, in applying the mechanical powers, we are not confined to one, but may combine, in various ways, several of them; for instance: Suppose we wished to move a heavy building. By means of levers and screws we would raise it from its position and place rollers under it; and, to diminish friction, plank may be laid down as a railroad, for the rollers to move upon. A system of pulleys, as represented in Fig. 39, may now be attached to the building, and to some immoveable point, as a tree, or a post made sufficiently firm, and then the line of rope, to which the power would otherwise be attached, made to pass round a cap-

* We once heard a very eccentric and original gentleman remark, that evil, in the moral world, was like friction in the mechanical world. He did not explain his meaning, and of course was not understood; and thus he acquired the reputation of speaking in an unknown tongue.

stan, as in Fig. 36, and then horse-power may be applied to the levers of the capstan. In this way immense power may be concentrated. In a similar manner, the power of the wheel and axle may be applied to the lever of a *screw;* and, if to Hunter's screw, the power would be immense. But here, as elsewhere, the extent of its action would be proportionally small.

But it is useless to state instances of the combinations of the simple machines, for they may be as various as the permutation of their number; and no intelligent reader can be ignorant of their general combinations.

Notwithstanding the vast amount of time and thought that men have expended, on the nature and construction of machinery, no power has been, or can be, created. It is true, power may be *purchased* at the expense of time and velocity—and it must be fully paid for; besides the extra charges for friction, rigidity of ropes, and imperfections in the construction of machines.

What then, may be asked, is the advantage of machinery? We shall not attempt a full answer to this question; for, he who does not at once, and as by intuition, perceive great advantages, cannot be enlightened by reading. We only remark, that machinery may enable a man to use his whole force, where otherwise he could use but part of it. For instance, winding thread or silk, unaided by machinery, he could turn but a single spool, and with it he is able to turn fifty spools at a time. But it is not merely to aid the powers of man that machinery is so valuable—by it the force, not only of the horse and ox, but the force of winds and waters are also brought into requisition and applied to the accomplishment of labor.

MOVING FORCES.

(Art. 46.) There are, as we have before observed, several original forces which are used as mechanical agents. They are, animal power, wind, water, and steam power.

Water power is not independent of gravitation. Gravity moves the waters, and the momentum of the water is the moving force. Gravity may be used to *regulate* force—either to concentrate it into an instant of time, or to expand it into long and continued action; but the orig-

inal force, in such cases, is commonly animal power. We have an example of the first in the operation of raising a great weight and letting it fall on the end of a stick of timber, as in *pile-driving*. Here animal, or some other power, is expended to raise the weight, and gravity concentrates all that force to react by percussion only for an instant.

We have an example of the second kind, in winding up a clock; here the force of winding, done in a short time, is regulated by gravity, to act during a long interval of time.

Thus gravity may be made to regulate force. The elasticity of springs also regulate force, but are never the origin of force. A watch runs by the force employed in winding it up—the springs and wheel-work only serve to regulate that force, and expand it over a longer period of time. The elasticity of springs also regulates the force applied to move a wagon or carriage. Without springs, some of the moving force would be lost by abruptly striking impediments, and by the general roughness of the road; but springs, by giving way, ease the body over obstructions: that is, the center of gravity, of the moving body, is carried along a more uniform line than it otherwise could be.

Momentum is also a regulator of force; and, to accumulate momentum, is the office of the *fly-wheel* in many machines. This wheel is of considerable weight in proportion to the machine; and, with this wheel, it requires some extra force to put the machine in motion: nor can it acquire full motion at once, but, when once in motion, it cannot be instantly stopped; nor can there be sudden alterations of motion. The machine must, therefore, run more regular than it could do without this appendage; and, by preventing fitful and jerking motion, there is less wear and tear of the machine, and all the force is appropriated to the proper working of the machine.

SECTION III.

Chapter I.—Hydrostatics.

Hydro and *statics*—water at rest, is the literal meaning of the term; but, in a more enlarged sense, it means the science which treats of the weight, pressure, and equilibrium of all kinds of fluids in a state of rest.

A fluid, is a general name given to all bodies whose particles easily move among themselves. But there are two classes of *fluids*—the *elastic* and the *non-elastic:* the latter are sometimes called liquids.

Common air and the various gasses are fluids. Water, wine, &c, may be called fluid or liquid. The first may be compressed into a smaller space, and, when the pressure is removed, they return again to their former state by reason of their elasticity. Water, and other liquids, are also slightly compressible, and of course elastic, but not sufficiently so to erase the distinction.

(Art. 47.) Solids press only in one direction, because one particle cannot move or change its position by the pressure of others; but, owing to the ease with which the particles of a fluid move, we can establish the following propositions:

Prop. 1. *Fluids at rest press equally in all directions.*

Conceive water to be at rest in any vessel, and conceive any single particle any where situated in the body—that particle being free to move, would move either to the right or left, or up or down, if there were more pressure in one direction than in another; and the fact that it does not move, shows that there is equal pressure in all directions.

Prop. 2. *The surface of a liquid, in any open vessel, is horizontal.*

In reference to all common vessels, such as buckets, tubs, &c., the fact is too well known for comment, and the reason too obvious for explanation. But, for the purpose of leading to less obvious facts, let us suppose a ves-

sel in the shape of the letter V, (Fig. 50,) both branches of equal size and open at both ends. Water, or any other liquid, turned in such a vessel would rise to the same height in both branches of the tube, on the principle of equal momenta; for the quantity of water, and inclination of the two branches are, by hypothesis, exactly the same. Now, let us conceive a vessel in the shape of Fig. 51, or a tube open at both ends, one branch perpendicular, the other of long inclination. Water turned into this vessel will rest at the same horizontal level, the same as in Fig. 50, notwithstanding there is much more water in the inclined branch of the tube than in the perpendicular; but the weight of the water in the perpendicular branch acts perpendicularly, with the full force of gravity, and the weight of the water in the other branch is resting on an *inclined plane*—and the same principle which governs momenta of solid bodies on inclined planes, will give equal momenta to liquids on every inclination, when *they stand at the same horizontal level.*

Fig. 50.

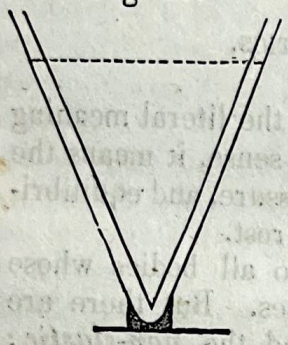


Fig. 51.

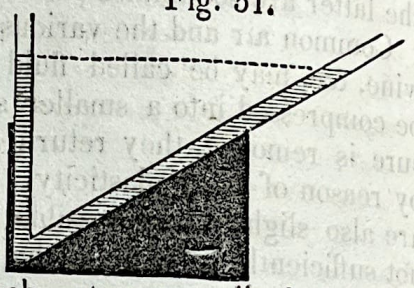
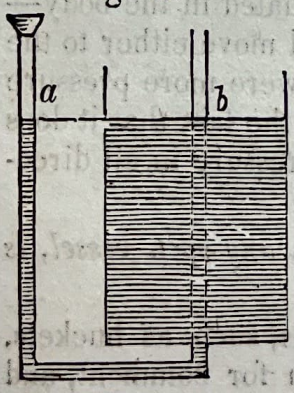


Fig. 52



Now suppose we have a vessel, as represented by Fig. 52; that is, a bent tube inserted into the bottom of any large open vessel; and conceive it to run up into the vessel—*not in reality, but in imagination.*

Now, suppose water to be in both the tube and vessel; we are to show that it will stand at the same horizontal level. The perpendicular column of water in the tube will balance an equal perpendicular column in the other branch of the tube, or in the *imaginary tube* which runs

up into the vessel.* This truth was explained by Fig. 50. Or, if the imaginary tube is conceived to run up into the vessel in any inclined direction, then the truth was explained by Fig. 51. Hence, if the water will stand on the same level in vessels represented by Figs. 50 and 51, it will stand on the same level in the vessel represented by Fig. 52.

Perhaps we may bring this truth to the mind more forcibly, by conceiving water turned into the tube at *a*, which would cause the particles of water to rise *in the imaginary branch* of the tube at *b;* but the moment they rose there, they would immediately flow to a level all over the surface of the vessel, however large the surface might be, and would continue thus to flow as long as a particle at *b* was higher than the particles at *a*. Therefore, whatever may be the size or shape of any *open* vessel, liquids will stand at the same height, or be on the same horizontal level in every part and branch of it.

In consequence of the pressure of fluids, and the facility with which they rise to their first level, fluids may be conveyed over hills and valleys in bent pipes, to any height which is not greater than the level of the spring from which they flow.

It is generally stated in the books, that the ancient Romans were ignorant of this principle, and hence constructed aqueducts across valleys at an enormous expense, giving to the water a regular slope; whereas, at the present day, a single pipe of cast iron is made to answer the same purpose, and even better. But the fact was not from the ignorance of the ancients of the principle,

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*Some authors have said, (and perhaps it is a common expression to say,) that a small column of water in a tube will *balance* the large quantity in the vessel. One author, speaking of a *coffee pot*, says—"Therefore, the small quantity in the spout balances the large quantity in the pot." But such expressions give vague and confused, if not incorrect, ideas. The small column in a spout, or tube, *reduced to a perpendicular*, balances only an *equal column* in the larger vessel, and the remainder is *balanced*, or upheld, by the sides of the vessel.

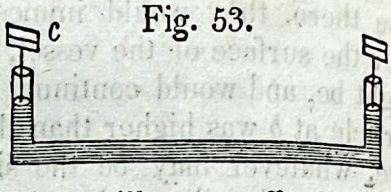
but because they had not any materials that would resist the pressure of water in pipes, when descending through valleys.

Fountains are formed upon the same principle: if, near the bottom of any vessel, a small pipe, bending upwards, be fastened, the water will spout through the pipe, and rise nearly as high as the surface of the water in the vessel.

(Art. 48.) We have practical application of this principle in the *water level*, as represented by Fig. 53.

Water, or any other liquid, will stand at the same level in the ends of the tube whether the tube itself is level or not; and, if the sight wires, as represented by *c* and *d*, are at the same height above the fluid, they will range off a horizontal level.

Fig. 53.

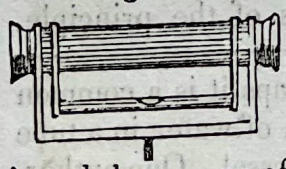


But this instrument is almost entirely laid aside in practice for a better one, the common

SPIRIT LEVEL.

This instrument consists of a glass tube, a little larger in the middle than at the ends, and filled with *alcohol*, (a liquid that will not congeal,) excepting a small space, in which is left a bubble of air, and the tube is sealed up. This bubble of air, being lighter than the liquid, will always be at the highest point. Hence, if the tube be placed so that the bubble rests in the middle, neither end of the tube is higher than the other—that is, the tube is on a level. A telescope is attached to the leveling tube, and so adjusted, by means of screws, that the line of sight through the telescope shall be in the same direction and parallel to the leveling tube. This instrument is very valuable, and much used in laying out and repairing railroads and canals, and in adjusting astronomical instruments. But its further description, or manner of using it, does not belong to this portion of science.

Fig. 54.



(Art. 49.) Proposition 3. *The relative pressure of wa-*

ter on the bottom of any vessel varies as the area of the base multiplied by the height of the water.

A clear conviction of the principle, embraced in this proposition, will lead a person through hydrostatics, and banish the dreaded hydrostatic paradox; and there will be no difficulty, provided the reader does not confound *pressure* with *weight*. They are the same in some cases, but very different in others.

If we put water into a tea-kettle, close up cover and spout, and put it over a fire, the internal *pressure* of the steam can be made to burst the vessel—yet the vessel and its contents will weigh no more just before it was ready to burst than when the water was first put in, because the pressure is in all directions, and, therefore, it will add nothing to the weight.

We now proceed with our proposition:

Conceive a vessel, as represented by (Fig. 55) standing perpendicular, of equal size from the bottom, and filled with water. We may imagine the water to be divided into a multitude of perpendicular columns, and each column composed of particles of water: the topmost particle is pressed only by its own weight, the particle immediately under it is pressed by the weight of two particles, the next below is pressed by three particles, and so on, the *pressure increasing in proportion to the depth.* The lowest particle will have all the particles in the column pressing on it and on the bottom of the vessel, and this will be true at the bottom of all the perpendicular columns; that is, there will be an equal pressure on equal portions of the bottom of the vessel: hence, on a double bottom or base, there will be a double pressure, &c. But the pressure is also increased in proportion to the depth: therefore, the *whole* pressure on the bottom must vary as the area of the base multiplied by the height of the column of water. In a regular vessel, like the one now under consideration, THE PRESSURE ON THE BOTTOM *is the same as the weight of the water*, and this plain case is very readily understood and easily comprehended: the difficulty, if any, is to come.

Fig. 55.

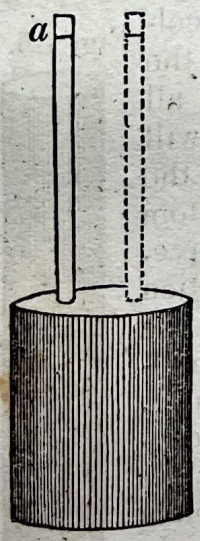
We have just said, that the pressure on the *bottom* of this vessel was equal to the weight of the water; but this is not the whole pressure of the water: there is also pressure on the sides. This may be shown by both reason and experiment. Bore a hole into the side of the vessel, below the surface of the water, and every one knows that water would run out; but it would not run out, if there were no lateral pressure.

A cubical vessel, filled with water—the pressure on the bottom is equal to the weight of the water.

As the pressure on any point on a side is in proportion to the depth, or distance from the top, therefore, the entire pressure on one side *is one-half* the pressure on the bottom, and the pressure on all the sides is twice the pressure on the bottom, and the whole pressure of sides and bottom *is three times the weight of the fluid.*

Now suppose we have a vessel of the same area of bottom as the last; that is, the same as represented by Fig. 55, and the altitude the same, but otherwise shaped, as represented by Fig. 56. We are still to show, that the pressure on the bottom of this vessel will be the same as on the bottom of the one represented by Fig. 55, or the same as though the sides of the vessel were perpendicular, but the weight of the water and the quantity will be much less. Suppose the vessel filled with water to *a*, near the top of the tube, and suppose an imaginary tube inserted in the vessel, as represented by the *dotted lines.* Now, if a hole were made and a tube actually set in, every one would admit that the water would ascend in such a tube up to the level of *a*, (Prop. 2.) But if the water would thus rise, there must be an upward pressure, under the top surface of the vessel, equal to the downward pressure of a column of water of the same height. But the cover of the vessel resists such pressure, and the *reaction* of that surface, *adds pressure to the bottom of the vessel,* and the amount of pressure on the bottom is, in fact, the same as if the sides of the vessel were perpendicular to

Fig. 56.



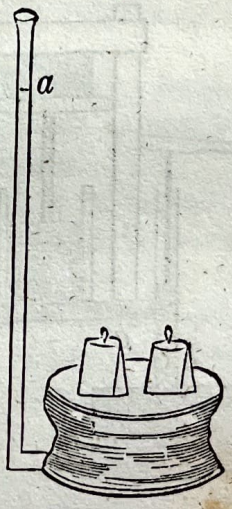
the top of the water. Or, the pressure on the bottom may be expressed by the *area of the base multiplied by the perpendicular height of the water*, whatever shape the vessel may be, or however much or little the vessel may hold. But, let it be observed, that when the pressure of a fluid is more than its weight, the fluid must be in a measure *confined*.

(Art. 48.) That a small column of water will cause as much pressure on the bottom of a vessel as a large column of the same height, has been called the hydrostatic paradox; but it is no more surprising than the fact, that a small weight at the end of the long arm of a lever will balance a larger weight on the short arm; and, by a little examination, we shall recognize the same principle governing both.

If the *rationale* of this fact is not yet clear, we may throw some light upon it by the hydrostatic bellows.

This is represented by Fig. 57. Two surfaces are connected together by strong leather, in the manner of a bellows, and a long perpendicular tube is connected with the space within. Water turned through the tube will press against the rising surface equal to the weight of a column of water whose base is equal to the base of the bellows, and altitude equal to the altitude of the water in the tube. Hence a little water turned into the tube at *a*, will cause the bellows to rise; but that *little water*, or an equal quantity, spreads all over the large surface, and the rise of that surface will be less in proportion. Now, if the large surface is 100 times the horizontal area of the tube, forcing down the water one foot in the tube will raise the surface only the one-hundredth part of a foot, and hence the momenta of the water in the tube is the same as in the bellows—a general principle in mechanical philosophy with which the reader must be familiar.

Fig. 57.



If it is still difficult to understand the *rationale* of this

principle, let the reader ask himself if it would not require a heavy weight on the bellows to throw a little water out of the tube, or to raise the water a little higher in the tube; and, if the mental response is, Yes, then we say the action and reaction are equal, and if it requires a great weight to move a little water, then, in the same circumstances, a little water will move a great weight.

On this principle we have the

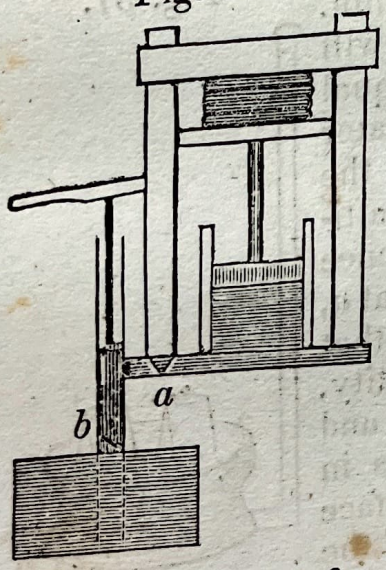
HYDROSTATIC PRESS.

This machine is represented by Fig. 58, and is much used in oil mills, and other places where great pressure is required.

In place of a high column of water, which would be inconvenient and pratically inefficacious, a piston is put into the tube which is connected with the cylinder, and also to the cistern, by pipes containing valves.*

When the piston rises, the pressure of the water closes the valve *a* that leads to the cylinder, and opens the valve *b* and lets water up from the cistern. When the piston presses downwards, the valve *a* opens and the valve *b* closes.

Fig. 58.



As the piston is worked by a lever power, we may put any convenient force on it, and thus dispense with a long tube. Now suppose the sectional arm of the cylinder is 50 times that of the tube, then the pressure of one pound on the piston will be 50 pounds on the large piston that plies in the cylinder. If we have a lever power of 20, worked by a man capable of exerting a force of 60 pounds, then the whole effective force of the press would be expressed by $60 \times 20 \times 50 = 60{,}000$ pounds, or thirty tons.

By diminishing the size of the tube and piston, or increasing the size of the cylinder, or both, and by giving

* The principle of the pump will be explained hereafter; here it must be used, and every one is supposed to understand its use, or at least its action.

a greater lever power and putting on more force, we can increase the pressure to any extent that the strength of the materials will bear.

Chapter II.—Specific gravity—its application.

(Art. 49.) Gravity is weight, and specific gravity is the specified weight of one body, compared to the weight of an equal bulk of another body taken as a standard. Water is the standard for solids and liquids, and common air is the standard for gasses.

Water will buoy up its own weight, and no more.

If a body is lighter than its bulk of water, it will float on water; if heavier than its equal bulk of water, it will sink in water; if just equal in weight, to the weight of an equal bulk of water, it will just remain in a counterpoise, between floating and sinking, and its specific gravity would then be the same as that of water.

For the sake of convenience, we will call the specific gravity of water 1, or 10, or 100.

Water varies its specific gravity according to temperature, as it becomes expanded, and of course is somewhat lighter as the temperature becomes greater.

At 40°, water has the smallest bulk, and of course the greatest specific gravity. At that temperature a cubic foot weighs 1000 ounces, or $62\frac{1}{2}$ pounds. But this is, at times, a very inconvenient temperature to obtain, and the common temperature of 60° has been suggested by some as more proper to use: at that temperature a cubic foot weighs $62\frac{35}{100}$.

If we suppose a body to weigh sixteen pounds in air and only fourteen in water, it is evident that the water buoys up two pounds, or the weight of the same bulk of water is two pounds, and the body weighs eight times as much as its bulk of water; therefore, the specific gravity of the body is 8, if we call that of water 1. If we call the specific gravity of water 1000, then the specific gravity of the body is 8000.

It is most convenient to call the specific gravity of wa-

ter 1. Then, to find the specific gravity of any other body, we have this general

RULE.—*Divide the weight of the body by its loss in water.*

EXAMPLES.

1. A body weighs 21 pounds in air and 7 in water, what is its specific gravity? *Ans.* $1\frac{1}{2}$.

2. A body weighs $12\frac{1}{2}$ pounds in air and 10 in water; what is its specific gravity? *Ans.* 5.

3. A body weighs 18 pounds in air and 16 in water, what is its specific gravity? *Ans.* 9.

4. A body weighs $11\frac{1}{2}$ pounds in air and $10\frac{1}{4}$ in water; what is its specific gravity? *Ans.* $9\frac{1}{5}$.

The specific gravities of the metals are nearly as represented in the following table; some may be compressed a little under the hammer, which will increase the specific gravity a little.

Fine gold - - -	19.25	Steel, hammered - -	7.90
Standard gold - -	18.75	Steel, cast - - - -	7.84
Quicksilver - - -	13.58	Iron, hammered - -	8.00
Lead - - - - -	11.35	Iron, cast - - - -	7.78
Copper, hammered -	9.00	Tin - - - - - -	7.29
" common -	8.90	Zinc - - - - -	7.00

(Art. 50.) The pupil will find no difficulty in obtaining the specific gravities of all bodies that sink in water, but such as float, like the different kinds of wood, require closer attention.

A body that will float, *has no weight in water;* but if a heavy body is attached to it, so that the whole will sink, the light body will lose its own weight and cause an additional loss of weight to the heavy body.

The general rule, as given in the last article, for finding the specific gravities of bodies, always holds good; that is, *divide the weight of a body by the loss it occasions when weighed in water*, and the difficulty is to discover that loss, but we will remove this difficulty by the following

EXAMPLE.

Wishing to obtain the specific gravity of a block of wood which weighed 10 pounds, I attached 27 pounds of

copper to it of a specific gravity of 9. The whole 37 pounds, weighed in water only 5 pounds. What was the specific gravity of the wood?

N. B. The loss in water was 32 pounds—but 27 pounds of copper, of a specific gravity of 9, when weighed in water must lose 3 pounds. Therefore, 29 pounds was the loss occasioned by the buoyancy of the wood. Hence the specific gravity of the wood must be $\frac{10}{29}$, water being 1.

From this example we may draw the following rule to find the specific gravity of any body that will float on water without dissolving or mixing with the fluid.

Weigh the body; attach a definite weight of a heavy body, of known specific gravity, sufficient to sink the whole.

Weigh the compound mass in water and note the loss. Divide the weight of the heavy body by its specific gravity, and subtract the quotient from this loss.

Divide the weight of the light body by this remainder, and the result is the specific gravity sought.

2. A certain piece of dry pine timber, which weighed $4\frac{1}{2}$ pounds, was attached to 20 pounds of iron, (specific gravity 8,) and the whole, weighed in water, weighed only $5\frac{3}{4}$ pounds; what was the specific gravity of the pine?

Ans. 0,277 nearly.

3. A piece of oak timber, weighing $17\frac{1}{2}$ pounds, was attached to 20 pounds of iron, and the whole, when weighed in water, weighed $15\frac{1}{4}$ pounds; what was the specific gravity of that piece of oak? *Ans.* 0,886+.

4. Ten pounds of iron and 2 pounds of cork were attached, and the whole mass barely sank in water; what was the specific gravity of that cork? *Ans.* 0.186+.

(Art. 51.) When we have a definite bulk of any substance, we can determine its specific gravity by proportioning its weight to the weight of an equal bulk of water.

For instance: a cubic foot of water weighs $62\frac{1}{2}$ pounds; and, of course, if a cubic foot of any other substance, or any other liquid, weighed more, its specific gravity would be greater; if less, less. That is

As the weight of any bulk of water is to the weight of the same bulk of any other substance, so is the specific gravity of water to the specific gravity of that substance.

By this rule we can find the specific gravity of all substances consisting of particles, such as sand, powder, flax-seed, wheat, corn, &c; also, all kinds of liquids.

To secure great accuracy in the equal measure of bulk, it is proper to have what is called a specific gravity bottle—a glass vessel of large bulb and long narrow neck.

Accurately balance such a vessel in the scales, and then put, by weight, 100 ounces of water at the temperature of 60°, and make a permanent mark on the neck of the vessel where the water stands. The vessel is now adjusted for use.

The water turned out and any other liquid turned in it up to the same mark and weighed, the weight will at once indicate the specific gravity of the liquid, the specific gravity of water being 100, and, if we multiply by 10, we shall have the specific gravity of the liquid, that of water being 1000.

As the weight of the liquid is the result, no operation is to be performed, and no examples are necessary.

By this process, the specific gravity of the following liquids have been ascertained—water taken at 1000.

Acids, in general, are heavier than water.

Oils, in general, are lighter than water.

Sulphuric acid, concentrated	1825
Milk	1032
Proof spirit	923
Alcohol, of commerce	835
Alcohol, (perfectly pure)	797

Some wines are lighter than water, and are called light wines; others are heavier than water, and, in consequence, are called heavy wines. Champagne and Burgundy are of the former, and Malaga of the latter.

(Art. 52.) When two substances, of different specific gravities, unite together and form a compound mass, the specific gravity of the compound is very nearly the medium proportion to the quantities of the ingredients, but not quite. As a general thing, when two metals, or two liquids, unite, there is a little condensation and a little increase of specific gravity. For instance, if 10 pounds

of zinc and 10 pounds of copper are melted together, they will occupy a less space than the two separately, and the specific gravity of the compound (brass) will be a little, *and but a little*, greater than the mean between the specific gravities of zinc and copper. So in general with other bodies. On the supposition, however, that the specific gravity of a compound is proportional to the specific gravities of the ingredients used, we can determine how much water is put into milk, how much water into alcohol, and, on this principle, Archimides discovered how much silver had been substituted for gold in making Hiero's crown.*

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* NOTE. All these investigations can be made by the mathematical student in a very summary manner, by using algebraical equations drawn from the following consideration.

That, when we say that the specific gravity of a body is 2, we mean that it weighs twice as much as its equal bulk of water; when we say it is 3, its weight is three times the weight of an equal bulk of water; therefore, in general, when the specific gravity of a body is n, the body is n times heavier than its equal bulk of water. Hence, *if we divide the weight of any body by its specific gravity, the quotient must be the weight of an equal bulk of water.*

Now the specific gravity of bodies under consideration, may be known or unknown. If unknown, represent them by x or y, &c.; if known, by a, b, &c. Then, after weighing the bodies and their compounds, we can form equations, and their solution will give the unknown quantities sought.

EXAMPLES.

1. Two bodies, whose weights were A and B, and specific gravities a and b, were put together in such proportions, as to make the specific gravity of the compound mass c. What proportions of A and B were taken?

A quantity of water, equal in bulk to A, must weigh $\frac{A}{a}$,

A quantity " " " " " " B, " " $\frac{B}{a}$,

(Art. 53.) Specific gravity comes directly to our aid, when we have occasion to find the weight of a body from its bulk; or, its bulk or measure from its weight.

For instance, we may pick up the most irregular shaped

A quantity of water, equal in bulk to $(A+B)$, must weigh $\frac{A+B}{c}$;

Therefore, $\frac{A}{a}+\frac{B}{b}=\frac{A+B}{c}$; Or, $bcA+acB=abA+abB$;

Or, $b(c-a)A=a(b-c)B$.

Hence the quantities of each must be reciprocal to these coefficients; or, if we take one, or unity of B, we must take $\frac{a}{b}\left(\frac{b-c}{c-a}\right)$ units of A.

2. Hiero, king of Sicily, sent gold to his jeweler to make him a crown; he afterwards suspected that the jeweler had retained a portion of the gold, and substituted the same weight of silver, and he employed Archimedes to ascertain the fact, who, after due reflection, hit upon the expedient of specific gravity.

He found, by accurately weighing the bodies both in and out of water, that the specific gravity of gold was 19, of silver 10.5, and of the crown 16.5. From this data he found what portion of the king's gold was purloined. Repeat the process.

The preceding problem is the abstract of this, in which A may represent the weight of the gold in the crown, B the weight of the silver, and $(A+B)$ the weight of the crown; $a=19$, $b=10\frac{1}{2}$, $c=16\frac{1}{2}$.

Then if we take $B=1$, one pound, one ounce, or any unity of weight, of silver, the comparative weight of the gold will be expressed by $\frac{a}{b}\left(\frac{b-c}{c-a}\right)$.

That is, for every ounce of silver in the crown, there were $4\frac{2}{3}\frac{}{5}$ ounces of gold. If clearer to the pupil, he may resolve this problem as an original one, without substituting from the abstract problem.

3. I wish to obtain the specific gravity of a piece of wood that weighs 10 pounds; and as it will float on wa-

stone in a field, and, by weighing it, and knowing its specific gravity, (which we always can know,) we may determine the number of cubic feet or inches in its contents.

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ter, I attach 21 pounds of copper to it, of a specific gravity of 9. The whole mass, 31 pounds, now weighed in water, weighs only 4 pounds; hence 27 pounds of the 31 are buoyed up by the water; or, we may say, the same bulk of water weighs 27 pounds. Required the specific gravity of the wood.

Let s represent the specific gravity of the wood.

Then $\frac{10}{s}$ = the weight of the same bulk of water.

And $\frac{21}{9}$ = the weight of water of the same bulk as the copper.

Hence, $\frac{10}{s}+\frac{7}{3}=27$, Or, $s=\frac{30}{74}=,405$ nearly.

4. Granite rock has a specific gravity of 2. A piece that weighs 40 ounces, being weighed in a fluid, was found to weigh only 21.5 ounces. What was the specific gravity of that fluid?

The weight of the fluid, of the same bulk as the piece of granite, was evidently 8.5 ounces. Let s represent its specific gravity.

Then $\frac{8.5}{s}$ = the weight of the same bulk of water; also $\frac{30}{3}=10$ = the weight of the same bulk of water.

Hence $\frac{8.5}{s}=10$. Or, $s=.85$ *Ans.*, which indicates impure alcohol.

5. The specific gravity of pure alcohol is .797; a quantity is offered of the specific gravity of .85, what proportion of water does it contain?

Let A equal the pure alcohol, and W equal the water: then $\frac{A}{.797}+W=\frac{A+W}{.85}$.

Ans. The resolution of this equation shows 1 portion of water to 2.255+ portions of alcohol.

For example, we will suppose a certain stone, or piece of rock, weighs $15\frac{1}{2}$ pounds, and its specific gravity is $3\frac{1}{4}$; how many cubic inches does it contain?

Divide $15\frac{1}{2}$ by $3\frac{1}{4}$, and the quotient is $4\frac{10}{13}$ for the weight of an equal bulk of water. But a cubic foot, or 1728 cubic inches, of water weighs $62\frac{1}{2}$ pounds, therefore we have the following proportion:

As $62\frac{1}{2}$: $4\frac{10}{13}$ :: 1728 : to the number of cubic inches in the stone, which gives 131,8+, the answer.

A multitude of similar examples might be given, but we think the principle has been fully illustrated.

We give one or two reverse examples:

1. A round stick of timber is 50 feet long and $2\frac{1}{2}$ feet in diameter; the specific gravity of the wood being ,7, what is the weight?

Solution.—$(2.5)^2 \times ,7854 \times 50 \times (62.5) \times ,7$ = the pounds in weight, or $5\frac{3}{10}$ tons nearly, 2000 pounds being called a ton.

2. An unladened ship is resting in still water. The medium length of the ship is 120 feet, and the medium width 20 feet; the sides nearly perpendicular. After receiving cargo, she sank three feet deeper in the water. How many tons were put in? *Ans.* 207.

When we know the whole quantity of water displaced by any ship or vessel, we of course know the whole weight of ship and cargo.

Chapter III.—Hydraulics—the natural run on rivers—machines for raising water—barker's centrifugal mill.

The term Hydrostatics, means water at rest; the term Hydraulics, means water in motion. All motion of a body must be in proportion to the impelling force. We have shown, in Art. 47, that the pressure of water at the side, or bottom of any vessel, is in proportion to the depth or distance below the surface.

(Art. 54.) *The velocity with which a fluid issues through a small orifice, in the bottom or side of a vessel kept con-*

stantly full, is equal to the velocity of a body falling freely from the level of the surface to the level of the orifice.

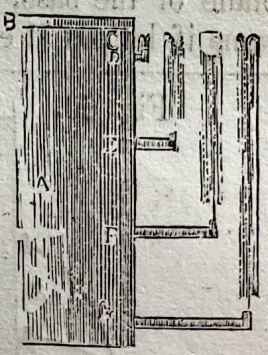
Let us conceive *one particle* of water rushing out of an orifice in the side of a vessel. It rushes out by gravity acting on it and on *each particle* of water in the vessel above it.

Now let us conceive a particle of water falling freely from the same height. It falls by gravity acting on it, and it acts on it all the way down, the same as though it were another and another and another particle—that is, gravity causes the same force to accumulate, acting on one particle as it occupies the perpendicular space, as it would acting at once on all the particles which fill up an equal perpendicular space. Hence, the force which impels a particle of water is the same, whether it fall freely through a certain height or is pressed by a column of water of the same height; but equal forces on the same body give equal velocities; thus the proposition is proved.

As this is a very important truth, and lest our demonstration should prove too metaphysical for some readers, we subjoin the following experiment and illustration:

If a pipe, or several pipes, be inserted in the side of a vessel constantly full of water, as represented in Fig. 59, and the pipes turned upward, forming tubes; it has been shown, in Art. 47, that water will find its level; hence there is an upward pressure, at the bottom of the pipe, sufficient to drive the water up the tube to the same level. But whether the tube be there or not the upward pressure is the same, and (independent of the resistance of the air and the falling drops) the water will project upwards to the level of the water in the vessel. But, when bodies ascend to any perpendicular height, they must start with the same velocity as they would acquire by falling freely through the same height, (Art. 8.)

Fig. 59.



Hence, water gushes out of the bottom or side of a vessel with the same velocity that a falling body acquires in

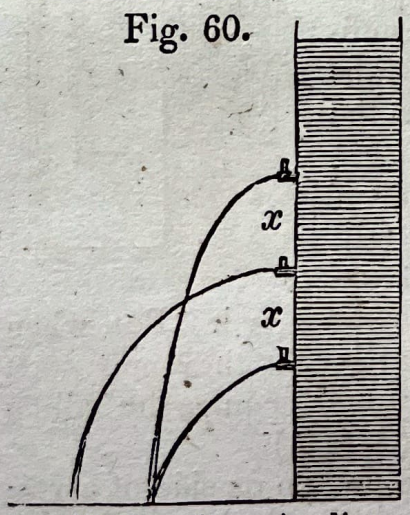
descending through a perpendicular distance between the level of the water and the level of the orifice.

According to this proposition, the effect would be the same, whether water was let fall from a certain height on a water wheel or let out from the side of a cistern against the floats of the wheel. That is, *theory* makes no difference when no other facts or circumstances are taken into account. But the effect is greater to let the water out of the side of a cistern; for then we have the full velocity unimpaired, whereas the actual fall of water is considerably diminished by the resistance of the air.

(Art. 55.) We have seen, in the last article, that the velocity of water issuing out of a vessel, must be the same as the velocity of a body falling freely through the same distance as the depth of the orifice below the water. But we have shown, in the chapter on falling bodies, that the velocities are in proportion to the *square roots* of the fall; therefore, the velocities of water gushing out of vessels must be in proportion to the *square roots* of the depths from which it is let out.

(Art. 56.) It has often been decided, by both *theory* and experiment, that a stream of water, projected *horizontally* from a vessel, would strike a *horizontal* base, and make the greatest horizontal range, when the orifice was exactly midway between the surface of the water and the plane of the base, and the horizontal range would be the same if let out at equal distances from top and bottom.*

Fig. 60.



* Note. For the benefit of the analytical student, we give the following investigation of this truth.

Conceive a vessel, or cistern, as represented in the figure, and take a for one-half of the altitude, or one-half of the depth of the water.

Take x, any distance less than a, and make an orifice at $(a+x)$ distance from the bottom. Then it will be $(a-x)$ distance from the top. Also, make

That is—the streams will range as represented in (Fig. 60.)

(Art. 57.) The quantity of water which will run through an orifice in a given time, will of course depend on the size of the orifice and the amount of pressure; but it is not to be expected that experiments, as to the

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another orifice, or conceive one to be made, at $(a-x)$ distance from the bottom, then it will be $(a+x)$ distance from the top. Now let v represent the velocity with which a particle of water would rush out of the upper orifice, and v' the velocity at the lower orifice.

A particle of water, when projected horizontally from either orifice, will reach the plane, or horizontal base, in the same time as it would require to fall from a state of rest, (Art. 17.) Now let t represent the time a particle of water would occupy in passing from the upper orifice along the curve to the plane. Also, let T represent the time required for a particle to pass from the lower orifice to the plane.

We have now completed our notation.

The horizontal range of a particle of water from the upper orifice, will be represented by the product, tv. The horizontal range of a particle from the lower orifice, will be represented by the product, Tv. We must now examine the relation of these products:

By (Art. 55,) we have $v : v' :: \sqrt{a-x} : \sqrt{a+x}$,

By (Art. 17,) we have $t : T :: \sqrt{a+x} : \sqrt{a-x}$;

By multiplying these proportions and reducing the last couplet, we have $tv : Tv' :: 1 : 1$;

Or, $tv = Tv'$.

That is, the horizontal ranges of two horizontal jets of water, equally above and below the center, will be equal.

But all the horizontal ranges are expressed by the product $\sqrt{a-x}\ \sqrt{a+x}$, or $\sqrt{a^2-x^2}$, and this product is evidently greatest when $x=0$, or when one orifice is made exactly half way between the top and bottom; and we further observe, that this maximum range is equal to a, half of the altitude of the perpendicular column of water.

quantity of water run out, will exactly agree with theory, both on account of the resistance of the air, the resistance of the water against the sides of the orifice, and the oblique motion of the particles of the water in entering it. For, it is not merely the particles situated immediately in the column over the hole, which enter it and issue forth, as if that column only were in motion; but also particles from all the surrounding parts of the fluid, which are in a commotion quite around; and the particles thus entering the orifice in all directions, strike against each other, and impede one another's motion: from which it happens, that it is the particles in the center of the orifice only that issue out with the whole velocity due to the entire height of the fluid, while the other particles towards the sides of the orifices pass out with decreased velocities.

The quantity of water discharged from any reservoir, or vessel, by an orifice, does not alone depend on the size of the orifice and the amount of the pressure; other circumstances must be taken into consideration, such as opposing currents and friction. We might, at first, suppose that an orifice, without a tube, would discharge the greatest quantity of water in a given time, but, it has been found by experiment, that a tube, whose length is twice the diameter of the orifice, other circumstances being equal, will discharge the greatest quantity of water in a given time.

"Such an aperture discharged eighty-two quarts, in the same time that another vessel of tin, without the pipe, discharged sixty-two quarts.

This surprising difference is accounted for, by supposing that the cross currents, made by the rushing of the water from different directions towards the orifice, mutually interfere with each other, by which the whole is broken, and thrown into confusion by the sharp edge of the tin, and hence the water issues in the form of spray, or of a screw, from such an orifice. A short pipe seems to correct this contention among opposing currents, and to smooth the passage of the whole, and hence we may observe, that from such a pipe, the stream is round and well defined.

The sudden turns, or angles of a pipe, are also found to be a considerable obstacle to the rapid conveyance of the water, for such angles throw the fluid into eddies or currents, by which its velocity is arrested.

In practice, therefore, sudden turns are generally avoided, and where it is necessary that the pipe should change its direction, it is done by means of as large a circle as convenient.

An inch tube of 200 feet in length, placed horizontally, will discharge only one-fourth part as much water as a tube of the same diameter an inch in length; hence, in all cases where it is proposed to convey water to a distance in pipes, there will be a great disappointment in respect to the quantity actually delivered, unless the engineer takes into account the friction and the turning of the pipes, and makes large allowances for these circumstances. If the quantity to be actually delivered ought to fill a two inch pipe, one of three inches will not be too great an allowance, if the water is to be conveyed to any considerable distance.

In practice, it will be found that a pipe of two inches in diameter, one hundred feet long, will discharge about five times as much water as one of one-inch in diameter of the same length, and under the same pressure. This difference is accounted for, by supposing that both tubes retard the motion of the fluid, by friction, at equal distances from their inner surfaces, and, consequently, that the effect of this cause is much greater in proportion, in the small tube, than in the large one.

(Art. 58.) The flow of *rivers* have been theoretically considered as the fall of bodies down *inclined planes*, but the conclusions drawn from this theory do not accord with experience.

The fall of three inches per mile in a smooth straight channel, would give, by calculation, a flow of about one and a half miles per hour; but the actual flow is about twice that, or three miles per hour. The velocity of a stream does not depend alone on the amount of declivity, the larger the quantity of water the greater the momentum and comparatively less is the friction: hence, we see the same stream moving slowly in a low stage of water

and much more rapidly when the water is high. In the latter case it has been said, that a river is running over a river.

Rivers flow with a much *less visible* velocity than the theory of inclined planes would give to them. When the fall is very slight, the water flows much more rapidly than computation assigns; and, when the fall is comparatively great, the velocity of the stream is much under computation.

The Ohio, at Pittsburgh, is only 675 feet above the level of the sea, and to fall these 675 feet it flows a distance of more than 2000 miles, and requires about forty days time.

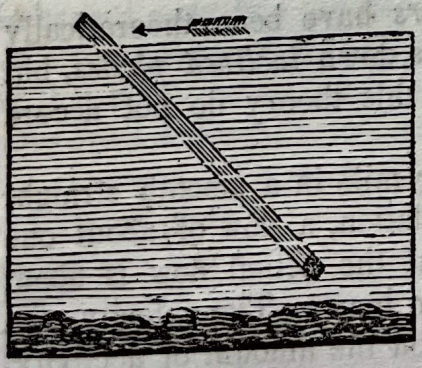
But it is not the whole body of a river that flows at the rates we have mentioned; it is the top of the stream and the middle of the current; for the friction of the banks and bottom, greatly impede the velocity. Hence, if a vessel or raft sink deep into the water and float down the stream, the floating sticks and pebbles will flow past it.

Hence, to measure the quantity of water that flows down a stream, we must measure the mean volume and the mean velocity of the current.

For this purpose we must load one end of a stick, to such a degree that the whole will just float—one end near the bottom and the other just above the surface of the water, as represented by Fig. 61.

Choose some portion of the channel, of about equal width and depth from bank to bank, and put the float in about the middle of the stream. Then by a watch observe how far it flows down in any definite time, say ten minutes, and measure the distance on the bank. Again put the float in, opposite the same points on the bank, and let it flow down near the sides of the river, and repeat the experiments several times near the middle and both banks, noting the distance each time; add the distances together and divide by the number of experi-

Fig. 61.



ments—the quotient will be the medium velocity of the whole body of water. Then, by measuring the average cross section, we find how many cubic feet of water flow down in ten minutes, and, of course, in one minute or an hour. We are not particular to give an example, for the result would be only approximate at best, and the real quantity would vary, perhaps, for every day in the year.

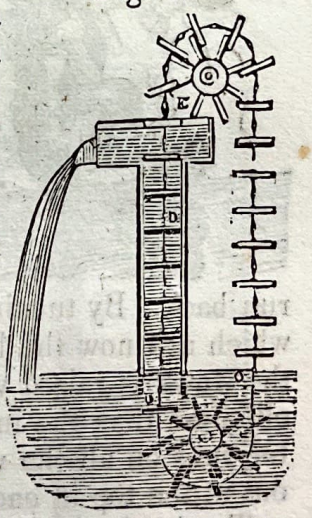
MACHINES FOR RAISING WATER.

(Art. 59.) Probably one of the earliest processes resorted to for raising water, was the common bucket and rope, either raised by the hands, or drawn up by a windlass, as in our common draw-wells. But the comparatively small quantity of water that can be raised at once, by the use of a single bucket, confines its employment to domestic or occasional purposes.

The chain-pump is a much more efficient engine, though very similar in its mode of action to the preceding.

The figure below indicates the form of this apparatus, which consists of a number of flat plates or disks of wood or metal, usually square, connected together through their centers by an iron rod, with joints between each board, so as to permit them to turn with nearly the same freedom as if they were connected by a chain. By attaching a winch to the upper wheel, these disks or plates drawn up by the revolving chain, form so many buckets filled with water, which they carry up and discharge into a cistern above, or when used as they commonly are on shipboard, into a pipe that may discharge it again into the sea. The machine may be set in motion by a winch, or other means employed to turn the upper wheel. The chain-pump will act with greater effect when the cylinder can be placed obliquely than when its direction is exactly vertical.

Fig. 62.



In ancient times water was raised by friction ropes;

that is, loose twisted ropes, running over a wheel, which dip into the water, and, as they are drawn up, bring water with them—on the same principle that water may be lifted out of a tub by means of a common swab or mop. But this method involves a great loss of force, as much of the water that is lifted part way up falls back again into the vessel.

The common pump, and the forcing pump, are now the most efficient machines for raising water; but the principle of these depend in a great measure on the pressure of the atmosphere; therefore we cannot treat of them until after we have examined *Pneumatics*, and at present we must be confined to such machines as require no aid from atmospheric pressure.

Among these, one of the most curious as well as most ancient, is *Archimedes' Screw*, said to have been invented by that philosopher and used for draining the lands of Egypt more than 2000 years ago.

This machine consists of a tube coiled round a shaft, and the whole standing in an inclined position as represented in Fig. 63. The machine must have such an inclined position, that the portions of the tube under the shaft will be lower than the next half turn towards the bottom, so that if water once gets into the lower coils of the tube it will not run back. By turning the shaft with the crank, the points which are now the lower coils of the tube are raised, and the water is raised with them, and raised to a greater inclination than the inclination of the shaft: hence the water runs on all the while, runing down hill, until it pours out at the top at each turn of the shaft.

Fig. 63.

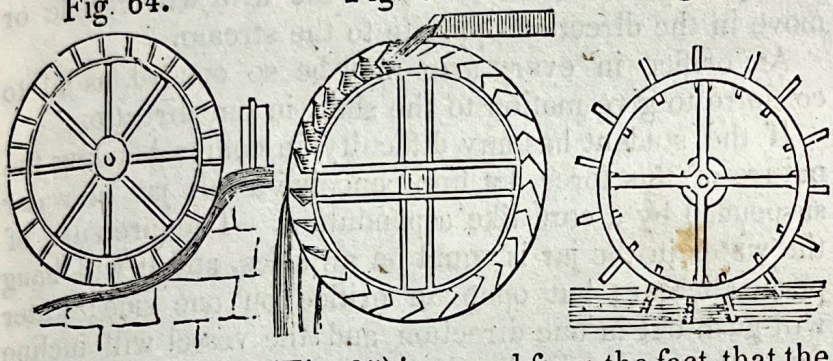
To clearly understand this, conceive a rifle ball or buck shot in the lower coil of the tube at *e*. Now turn the shaft; the tube will be lifted up and the ball will roll on, and in one complete turn the ball will be at *g*; and of course will finally roll out at the top of the tube. The

same will be true of a drop of water, or any number of drops.

WATER WHEELS.

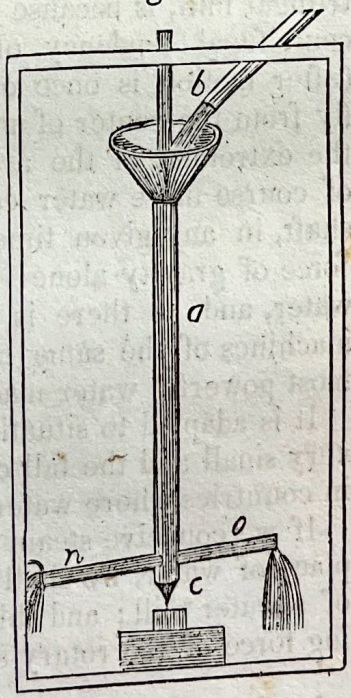
(Art. 59.) Water wheels are of three classes: the undershot, the overshot and the breast wheel. A simple glance at the next cut will distinguish them. The undershot wheel (Fig. 66) is chiefly used where there is a sufficient body of water and little fall. The water shoots under the wheel and moves it by impact against the float boards.

Fig. 64. Fig. 65. Fig. 66.



The overshot wheel (Fig. 65) is named from the fact, that the water shoots over it, and it is used where there is a small body of water with a considerable fall, and the size of the wheel may be decided by the fall of the water.

Fig. 67.



The breast wheel is medium in character between the other two, and it combines the advantage of both. This is adapted to situations where the supply of water is generally sufficient but not always abundant. It runs with less friction than the overshot, because the water has a tendency to lift it on the axis of motion, whereas the water in the buckets of the overshot wheel add weight on the axis.

In addition to these we have Barker's centrifugal mill, acting on the principle of hydros-

tatic pressure. It consists of a funnel shaped cylinder, standing perpendicular, with several horizontal arms, as represented in Fig. 67. Water is let in at the top, and, were no orifices open at the arms, the internal pressure of the water would be everywhere alike—and of course no motion. But an orifice being open on one side of an arm, the internal pressure is thereby taken away at that place, and the water runs out; but the pressure on the other side of the arm continues as before, and by this excess of pressure on one side, the arm will recede or move in the direction opposite to the stream.

An orifice in every arm may be so opened, as all to conspire to give motion to the shaft in one direction.

If the student has any difficulty in comprehending the nature of this force, let him conceive a tall jar of water suspended by a cord like a pendulum. The pressure of the water in the jar is equal on all sides, and it will hang perpendicular; but open an orifice on one side; water will gush out in one direction and the vessel will incline from the perpendicular in an opposite direction. The force which causes this inclination, gives motion to Barker's *centrifugal mill*. The reason why it is called centrifugal mill, is because it obtains additional force by the centrifugal tendency of the water: that is, the water (after motion is once obtained) has a great tendency to fly from the center of motion; hence it runs quicker to the extremity of the arms than it otherwise would, and of course more water can pass down the perpendicular shaft, in any given time, than would pass down by the force of gravity alone; and as there need be no waste of water, and as there is much less friction than in other machines of the same magnitude, this is said to be the most powerful water machine yet known.

It is adapted to situations where the stream of water is very small and the fall considerable; but it is rarely used in countries where water will freeze.

If we conceive steam to pass through the machine in place of water, we shall then have a steam mill in place of a water mill; and this is in fact the principle or moving force of the rotary steam engine.

CHAP. IV.—PNEUMATICS—AIR—ATMOSPHERIC PRESSURE—AIR PUMP—BAROMETER—PUMPS—SYPHON.

(Art. 60.) The word Pneumatics is of Greek origin, and signifies *breath* or *air*; but, at present it is understood to comprehend all the facts and philosophical inductions pertaining to the weight, pressure, force and elasticity of all or any elastic fluid.

We, and all animated creation, live in a *fluid*, as well as *fish*. We live in *an elastic* fluid; they in comparatively a non-elastic fluid. We live in a light fluid, they in a ponderous one.* Air is as necessary for our existence as water is for theirs. A fish may not be sensible of the great pressure of water, and, physically, we are as insensible of the great pressure of the air—we only come to the knowledge of it by reflection and experiment.

Pure air, and many of the gases, are perfectly transparent, and of course invisible; and this is nearly true of pure water—but both are blue, or reflect the blue color of light, hence the deep blue sea, and azure sky.†

Vapors are elastic fluids, produced from liquids or solid bodies, through the agency of heat, and, when the heat is withdrawn, return again to their original state: such is *steam*.

While in a state of vapor, steam and vapor have the same mechanical properties as air and gases.

Although air is transparent, invisible, and we are insensible of its pressure—it being equal in all directions—we are yet fully sensible of its existence, for we feel it by the breeze that fans us and the hurricane that spreads destruction around us. It presses into every crevice and fills all space in and around the earth not actually occupied by other bodies.

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*A cubic foot of air weighs little more than one ounce, a cubic foot of water weighs 62½ pounds.

†When we view a small quantity of air or water, we perceive no color; but this does not prove them colorless: for large quantities show color. Transparent liquids, slightly colored, do not show color in small quantities, as may be seen by the following experiment. Tinge some water by a little Indigo, or sulphate of copper, so that it has a decided blue appearance. Put a little of this into a small glass tube, and it will appear quite colorless.

Air is elastic.

This is shown by experiment. An inflated bladder may be compressed; but, on removing the compressing force, it immediately returns to its former shape and position. Take a tumbler, or tall glass jar, and plunge its open month down into a vessel of water; the air in the tumbler or jar will be compressed into a smaller space, but its resistance can be felt the same as the elasticity of a perfect spring, and the more the compression the greater the resistance, and however long the compression may be continued the air will return to its former bulk whenever the pressure is removed. This shows that air is permanently as well as perfectly elastic.

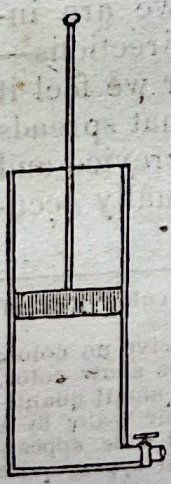
The elasticity of air is practically illustrated by its application in the forcing pump and water engine, commonly called fire engine, because it is only applied to extinguishing fires.

These instruments, or engines, will be explained in a subsequent article.

(Art. 61.) We have decided, in Hydrostatics, that the pressure of water on the bottom of a vessel, or on any portion of the bottom, say one square inch, is equal to the entire weight of the whole perpendicular column of water above.

So the pressure of air at the surface of the earth, on a square inch, must be equal to the entire weight of the whole perpendicular column of air above; but, as we do not feel this pressure, it being counterbalanced by pressure in all directions, how are we to render it sensible and determine its amount? When this is done, we are complete masters of the whole science of pneumatics.

Fig. 68.



For the most direct and simple experiments we require a strong tube and piston, with a stop cock at the bottom, as represented by Fig. 68.

The inside of the tube must be straight and smooth, and the piston fitted to work air tight and as easy as possible.

When the stop cock is open, the piston may be drawn up or pushed down with equal ease;

because the natural pressure of the air is the same above and below. Now push the piston down, and then close the stop cock.

Now, if we attempt to raise the piston, we shall find it will require great force, and more as the piston is larger: and the reason is obvious, for the air cannot go through the stop, *c*, to press upwards on the under side of the piston: and to lift the piston, we must necessarily lift the whole perpendicular column of air above it; and we find that it requires a force of about 15 pounds to every square inch of the piston to move it. Thus the pressure of the air becomes sensible.

Now let us suppose the tube, as represented in the last cut, to be small and long, the piston pushed down to the bottom, and the stop cock open. Then, the lower end and stop plunged into water and the piston drawn up. By the pressure of the air, water will run in at the open orifice or stop and follow the piston, until the pressure of the column of water balances the pressure of an equal column of air.

It is found, by experiments, that water will follow such a piston between thirty-two and thirty-three feet, and no further.

But a column of water, of one square inch of base and thirty-three feet high, will weigh fifteen pounds, or nearly so: hence, we know that the pressure of the atmosphere is nearly fifteen pounds to the square inch.

If any one shall have serious doubts that it was the pressure of air that drove the water up the tube and sustained it there, he might be convinced by inserting the tube through the head of a barrel filled with water, and so closed up that the pressure of the air could not get to the water in the barrel. Then, if the piston shall be drawn up, the water will not follow.

It is the pressure of air which makes the water rise in a pump barrel, the same as in this tube; but, if the well is completely frozen over so that the external air cannot press on the water, the water will not ascend in the pump: and in cold countries this is not an unfrequent occurrence.

The experiment just described, to obtain the amount of atmospheric pressure, has perhaps never been made,

except incidentally by means of water ascending in pump barrels—because it is very troublesome and almost impossible to make, owing to the great length of the required tube, 33 feet. But if we take mercury (quicksilver) in place of water, we shall then require a tube only 30 inches long—for as mercury is heavier than water, of course the atmospheric pressure cannot sustain so high a column.

A column of mercury of about 29½ inches is sustained by the atmospheric pressure; but 29½ cubic inches of mercury weigh nearly 15 pounds: therefore we know that the atmospheric pressure is about 15 pounds to every square inch.

The column of mercury sustained by the atmosphere is not always the same, but variable; sometimes it falls as low as 28 inches, at other times rises almost to 31; and a *barometer* is nothing more than a column of mercury measuring the variable pressure of the atmosphere: but more of this hereafter.

Many experiments may be made, illustrating the elasticity, expansibility and pressure of the air, by any one who may have the requisite apparatus of tubes, receivers, and a good

AIR PUMP.

(Art. 62.) The air pump is an engine by which a portion of the air can be drawn out of any vessel that can be fitted air tight to the pump plate.

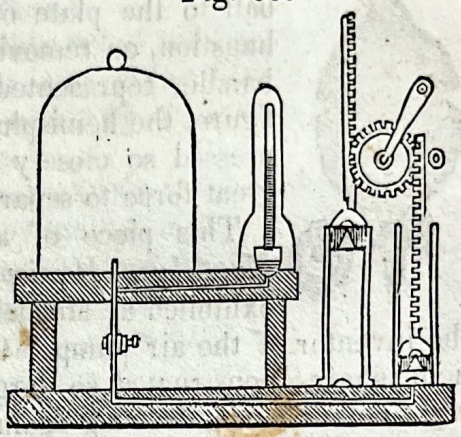
We shall not attempt a minute description of this instrument, for a little inspection of the following figure will give a clearer idea of it than whole pages of ever so careful composition. An air pump may have one or two pump barrels. Each barrel has two valves—one in the piston and one at the lower end of the barrel, both opening upwards.

A valve is nothing but a lid. The lid of a tea-pot which has no fastenings but the hinge may be called a valve. Upward pressure will open it, and downward pressure will close it.

The pistons in the pump barrels are worked up and down, by means of the winch which turns the wheel in opposite directions.

When either piston is descending, its valve opens by the greater pressure of air on the under side, and lets the pent air through. The lower valve of course is closed while the piston descends. When either piston is down and begins to ascend, the piston valve closes and the lower valve opens, and the air expands out of the receiver to fill up the whole space made by the ascending piston; as the piston descends again, this portion of expanded air is let through the upper piston, and is thus forced out.

Fig. 69.



In this manner the air keeps expanding from the receiver, opens the lower valve, and follows each rise of the piston, and is prevented from returning again to the receiver by the closing of the valve the moment the piston begins to descend. Thus the air in the receiver becomes more and more rarified by every rise of the piston, until it becomes too weak to open the lower valves, and then the effect of pumping will cease. It is therefore certain that a perfect void can never be obtained by an air pump.

The following experiments may be easily made with the air pump:

1. *To show a sensible pressure of air.* Put a receiver on the plate of the air pump. Before working the pump it can be taken off with ease, because the pressure of the air is the same both inside and outside. But work the pump and the air on the inside is rarified, and its pressure become less. It now requires considerable force to lift off the receiver, as the external pressure is greatest. No violent attempt should be made to lift it, as there would be great danger of its breaking.

The annexed, Fig. 70, represents two hemispheres of brass, closely fitted to each other at their edges. When these are put together, they can be pulled asunder with

very little force, so long as the pressure of the air acts on the inside as well as on the outside. But now join the parts together, and screw the ball to the plate of the pump. After exhaustion, on removing it and attaching the handle, represented at the bottom of the figure, the hemispheres will be found to be pressed so closely together as to require great force to separate them.

Fig. 70.

This piece of apparatus is called the *Magdeburg Hemispheres*, having been first exhibited at Magdeburg, by Otto Guericke, the inventer of the air pump. Guericke had a pair of hemispheres constructed so large, that sixteen horses, eight on each side, drawing against each other, were unable to pull them asunder.

2. *To show the elasticity of the air.* Place under the receiver of an air pump a bladder, which has been about half filled with air and firmly tied at the neck so as to prevent it from escaping; on exhausting the receiver gradually, the bladder will be seen to swell, from the expansion of the air within it; and if the exhaustion be continued long enough, the bladder will burst, from the elastic force of the air it contained, no longer counterbalanced by pressure on the external surface.

A square or flat glass vial, filled with air, well corked and fastened with wire, if placed under the receiver, will crack from the expansion of the air within it, as soon as the pressure is withdrawn from its surface by the exhaustion of the receiver.

Shrivelled apples, prunes, or raisins, with their skins unbroken, when placed under a receiver, on the air being exhausted, will become plump from the elasticity of the air included in those fruits; and thus a bunch of dried raisins may be made to assume the appearance of a fine cluster of grapes, and a similar apparent renovation may be effected on the apples and prunes; but, on readmitting the air into the receiver, the fruits will all resume the wrinkles which betray their age.

If we have a tall jar, or receiver, closed at the top and fitted with a stop cock at the bottom, and the whole fitted

to the air pump, we may partially exhaust it of air; then take it from the pump and plunge its lower end in water; open the stop and water will fly up into the vessel:

This is called, *Le jet d'eau.*

Water will fly up into this vessel until it condenses the air within to a density the same as the density of the air without, and the body of water which ascends shows how much air was pumped out.

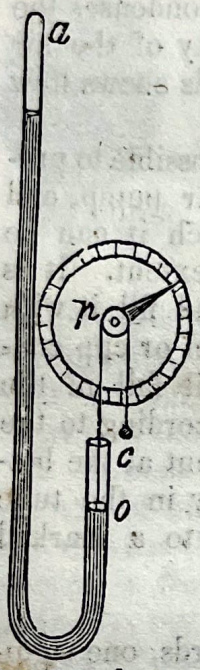
(Art. 63.) We have observed that it is impossible to produce a perfect vacuum by means of the air pump, and indeed we know of only one method by which it can be accomplished, and that to no considerable extent. It is to take a tube more than 31 inches long, and fill it with mercury; then carefully invert it in a vessel or cup containing the same fluid. The mercury will fall in the tube, to about 29 inches (more or less, according to the then pressure of the atmosphere,) and run out at the bottom into the cup, and all above the mercury in the tube is *void space.* The tube itself, appended to a marked scale, and properly secured at bottom, is a

BAROMETER.

This term is derived from two Greek words, one signifying to weigh, the other to measure—and, in fact, the instrument is one to measure the weight of the atmosphere As here described, it would be very difficult to use or transport: hence the necessity of a case, and some little mechanism. The mercury should not be in an open cup, as it would be very liable to spill, and would require a painful degree of caution in moving it; nor must the mercury be inclosed, for the pressure of the air could not act upon it: but this difficulty is remedied by inclosing the mercury in a leather cup, or rather bag, which, being elastic, the pressure of the atmosphere acts on and through it—on the mercury the same as though the mercury was not inclosed at all. Below the leather bottom there is a round plate of metal an inch in diameter, which is fixed upon the top of a screw, so that when the instrument is to be transported, by elevating this piece of metal, the mercury is thrown up to the top of the tube and thus kept from plying backwards and forwards, when the barometer is in motion.

To render the slightest variations of the pressure of the atmosphere perceptible, we have the *wheel barometer*, as represented in Fig. 71. The mercury rises in the short leg to the point *o*, where there is a small piece of glass floating on its surface, to which there is attached a silk string, passing over the pulley *p*. To the axis of the pulley is fixed an index, or hand, and behind this is a graduated circle, as seen in the figure. It is obvious, that a very slight variation in the height of the mercury at *o*, will be indicated by a considerable motion of the index, and thus changes in the weight of the atmosphere hardly perceptible by the common barometer, will become quite apparent by this.

Fig. 71.



As the column of mercury is sustained by the pressure of the column of atmosphere, it was readily inferred, that, at more elevated situations, the height of the mercurial column would be less; that is, as we ascend a hill or mountain the barometer would fall—and, on experiment, that was found to be the fact, an additional proof, if one is necessary, that it is the atmospheric pressure that sustains the mercury. By a multitude of careful experiments it has been found, that the mean height of the barometer is greatest at the level of the sea, and varies for the first 87 feet perpendicular altitude (other circumstances equal) $\frac{1}{10}$ of an inch. From this we infer at once, that $\frac{1}{10}$ of an inch of mercury weighs as much as 87 feet of the lower strata of the atmosphere. Consequently, 1 inch of mercury weighs as much as 10440 inches of air. But mercury weighs 13,57 times as much as water: therefore, divide 10440 by 13,57, and we have 769. nearly for the ratio between the weight of air and water; and as a cubic foot of water weighs $62\frac{1}{2}$ pounds, a cubic foot of air does not weigh quite one ounce.

The entire weight of the whole atmosphere that surrounds the earth, may be estimated by computing the entire weight of a mass of mercury sufficient to cover the

whole earth, and 29 $\frac{9}{10}$ inches deep. As the air is elastic and highly compressible, the lower portions must be more dense than the upper; hence another fall of one-tenth of an inch will correspond to more than 87 feet, and indeed it has been very difficult to obtain the exact law, corresponding between the fall of the barometer and the elevation of its place—but, nevertheless, approximate rules have been laid down to measure the height of mountains by the barometer.

Changes of temperature affect the pressure of the air, for cold contracts and heat expands it; therefore, to make actual barometrical measurements, regard must be had to the height of the thermometer as well as to the height of the barometer; and, furthermore, the increase of temperature expands the mercury in the tube of the barometer, and hence there must be two corrections corresponding to temperature.

By observations on the barometer, at different known altitudes, and aided by theory, it has been decided that the altitudes vary by an *arithmetical series*, and the density of the air in a *geometrical series*, and, at the altitude of seven miles, the density is only one-fourth of that at the earth's surface—and if this be true, the

Arithmetical series 7, 14, 21, 28, and the

Geometrical series $\frac{1}{4}$, $\frac{1}{16}$, $\frac{1}{64}$, $\frac{1}{256}$, &c., correspond.

The first series represents the altitudes in miles above the earth, and the second represents the corresponding densities at those heights, the density at the surface considered as unity. From this we learn, that at the height of $3\frac{1}{2}$ miles (which is about the elevation of our highest mountains) the density and pressure of the air is one-half what it is at the earth's surface—and this gives painful effects to the hasty traveller, who rapidly ascends a mountain—for the internal air in every part of his body, carried with him, is not counteracted by the external pressure, and hence the body and limbs have a tendency to swell, causing a general debility and pain. A slow and very gradual assent will avoid these effects, yet it is probable that the atmosphere is not sufficiently dense in such situations for healthful respiration.

The experiments of withered apples, dried fruits, &c.,

under the receiver of an air pump, are so many illustrations of the swelling of the veins, blood vessels, and other parts of the body on a mountain.

We do not feel at liberty to make comments upon the composition of the air, for that belongs to chemical and not to mechanical philosophy; but we cannot avoid mentioning the fact, that compressed air generates or gives out heat, and non-compressed air absorbs heat and thus produces cold: hence the lower stratas of the atmosphere will give out more heat, or absorb less, than the upper stratas—and this accounts for its being colder on the mountain than in the valley. The region of perpetual frost at the equator is about three miles high; in latitude 35°, about two miles; in 53° about one mile, and in the parallel of 80°, it comes nearly down to the surface of the earth.

It is an experimental fact, that air, suddenly and forcibly compressed in a tube, will give out sufficient heat to set light and highly combustible substances on fire.

(Art. 64.) The pressure of the atmosphere is not always the same in the same place; a fact that could not have been ascertained independently of the barometer.

The mercury varies from 28 to 31 inches, but it is rarely below $28\frac{1}{2}$, or above $30\frac{1}{2}$—it is commonly at 29.8 inches. It is very natural to suppose the variations in atmospheric pressure, are either in consequence of actual changes in the weather, or they produce changes. In short, they are either the cause or the effect—for any considerable change in the barometer is always accompanied by a change in the weather.

Generally, the rising of the mercury indicates the approach of fair weather; the falling of it that of foul weather.

In hot weather the fall indicates thunder.

In winter the rise indicates frost, and in frost, the fall indicates thaw, and the rise, snow.

If fair or foul weather *immediately* follows the rise or fall, little of it is to be expected.

If fair or foul weather continue for some days, while the mercury is falling or rising, a continuance of the contrary weather will probably ensue.

An unsettled state of the mercury indicates changeable weather.

By these rules it will be seen, that the words engraved on the plate are frequently calculated to mislead the observer. Thus, if the mercury be at *much rain*, and rise to *changeable*, fair weather is to be looked for. Again, if it be at *set fair*, and fall to changeable, foul weather may be expected.

As the variations of the barometer generally precede the variations of the weather, this instrument is said to indicate the weather, and thus in some instances has been invaluable—particularly to navigators and travellers.

One evening, a few years ago, a gentleman in New York was very desirous to start on a journey in an open carriage; but the appearance of the heavens gave every indication of rain, and he hesitated. But he was assured by another, who had consulted the barometer, that he could go without exposure, and that it would soon be fair weather. He accordingly started, and, in one hour's time, the clouds were passing away and the moon was shining brightly.

But at sea the barometer is most useful. Dr. Arnot gives the following incident, and the author of this work has witnessed several similar incidents:

"It was," says the Doctor, "in a southern latitude. The sun had just set with a placid appearance, closing a beautiful afternoon, and the usual mirth of the evening watch proceeded, when the captain's orders came to prepare with all haste for a storm. The barometer had begun to fall with appalling rapidity. As yet, the oldest sailors had not perceived even a threatening in the sky, and were surprised at the hurry and extent of the preparations; but the required measures were not completed when a more awful hurricane burst upon them, than the most experienced had ever braved. Nothing could withstand it; the sails already furled, and closely bound to the yards, were riven into tatters; even the bare yards and masts were in a great measure disabled; and, at one time, the whole rigging had nearly fallen by the board. Such, for a few hours, was the mingled roar of the hurricane above, of the waves around, and the incessant peals

of thunder, that no human voice could be heard; and, amidst the general consternation, even the trumpet sounded in vain. On that awful night, but for a little tube of mercury, which had given the warning, neither the strength of the noble ship, nor the skill and energies of her commander, could have saved one man to tell the tale."

(Art. 65.) We are now prepared to explain the action of the common water

PUMP.

The pump is nothing more than a tube open at both ends, in which works a water-tight piston, with a valve opening upwards; also another valve in a fixed position near the bottom.

We have seen, in Art. 61, that water will follow a piston drawn up in a tube to the height of 32 or 33 feet, but no farther. The force that causes water thus to rise, was formerly called suction—a word used to express the fact and hide our ignorance: we now know that it is the pressure of the atmosphere.

Air and water are both capable of being pumped out of a vessel; and, when the pump is ready, all we have to do, is to put the lower end in the water and work the piston. When the piston descends, the pressure of the air below it opens the valve and air comes through; then, when the piston rises, water follows to supply the air escaped: and thus, by several strokes of the piston, the air is pumped out and water takes its place. The further working of the piston throws out water.

Fig. 72.

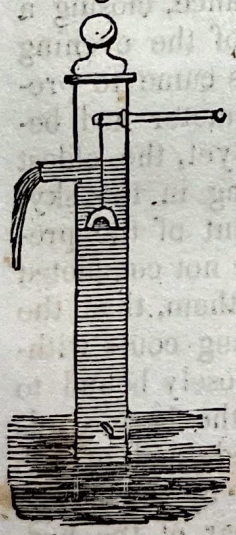


Fig. 72, represents a common pump, when the barrel or tube is filled with water. When the piston presses downwards, the water below opens its valve and comes above the piston; then, as the piston rises, it lifts the water out, and the pressure of the external air drives the water up through the lower valve to follow the piston.

If the piston could work perfectly air-tight, there

would be no use for the lower valve; but as air will, by degrees, pass through the upper valve, or around the piston, it would press the water down in the pump barrel if it were not for the lower valve, which closes when the pump is not in action and holds the water up.

When both valves leak, as is sometimes the case, the water will not long remain in the pump barrel, but will sink to the level of the water in the well. In such cases extra exertions have to be made to raise the water; or, if the leaks are great, it may be impossible to use the pump at all.

We cannot use a pump to raise water more than thirty-two or thirty-three feet, as the pressure of the atmosphere will not support a higher column of water.

When a pump is used to raise water thirty or thirty-two feet, it works very hard; for the operator in such cases must not only lift the piston and the water above it, but the whole pressure of the atmosphere above the piston: the external pressure of the air is all employed in sustaining the thirty-two or thirty-three feet of water in the pump barrel.

We may in fact raise water from any depth by this pump, provided we put the piston so low as to work within thirty-two feet of the level of the water in the well; but, when we have more than four or five feet of water above the piston, the weight of the water and the pressure of the atmosphere requires a great power to work the pump—and the pump itself must be very perfect, or it will soon become useless and out of repair. For these reasons pumps are very rarely put into deep wells.

When a pump is used to raise water only a few feet, it works very easy; for then the operator has only to lift the piston with the water above it, and only so much of the pressure of the atmosphere as is requisite to sustain the few feet of water in the pump barrel. We now pass to the

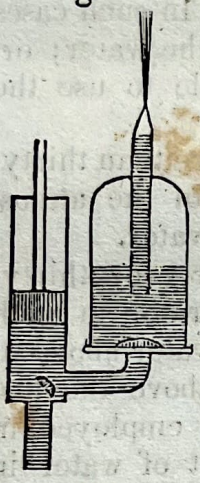
FORCING PUMP.

(Art. 66.) The forcing pump derives its name from the fact, that it *forces* the water into a side vessel in place of lifting it out like the common pump. This side vessel is sometimes called the air vessel—for it is closed at the

top so as to confine a body of air, and a water pipe runs through the top and passes down near to the bottom of the vessel, and when water is forced into this vessel above the bottom of the water pipe, the air in the vessel is completely confined.

The forcing pump is represented by Fig. 73. The piston has no valve. There is one valve in the pump barrel, and one in the tube that leads to the air vessel; both open upwards to let the water pass; but they shut when there is any excess of downward pressure, and thus prevent the water's return.

Fig. 73.



When the piston rises, the valve in the pump or piston barrel opens, and water comes through following the piston.

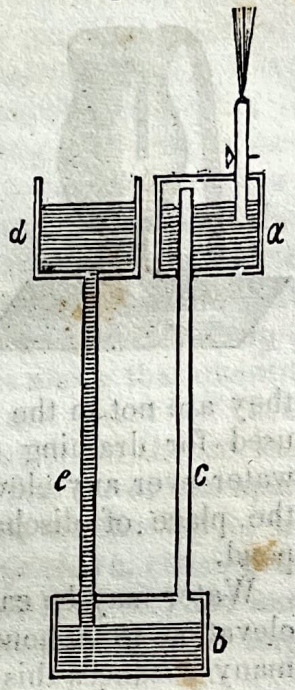
When the piston is pressed down, the valve in the pump barrel closes, and the valve in the tube that leads to the air vessel opens and water is forced through; and if the water pipe is stopped and water forced into the vessel, the air will be compressed into a smaller space, (and thus we have an experiment, showing the compressibility of air;) and the air, thus compressed, forces the water through the water pipe when vent is given. By a pump of good lever power, a good sized air vessel, and a small water pipe, a man can send a column of water 25 or 30 feet high.

When we have two pump barrels, one each side of the air vessel, and two pistons worked by a double lever on a center of motion, and the whole placed on a carriage, we then have a water engine, commonly called a *fire engine*—because it is applied to extinguishing fires. In whatever shape a fire engine may appear—whether square, cylindrical or oblong, it is one and the same thing, a forcing pump.

Hiero's fountain, represented by Fig. 74, acts upon the same principle as the forcing pump; but the power is only the pressure of a column of water, and it is only a philosophical toy—and for this reason it is with some reluctance that we give it place. The further explanation we extract from Comstock:

"The boxes *a* and *b*, together with the two tubes, are made air tight, and strong in proportion to the height it is desired the fountain should play. To prepare the fountain for action, fill the box *a*, through the spouting tube, nearly full of water. The tube *c*, reaching nearly to the top of the box, will prevent the water from passing downwards, while the spouting pipe will prevent the air from escaping upwards, after the vessel is about half filled with water. Next shut the stop cock of the spouting pipe, and pour water into the open vessel *d*. This will descend into the vessel *b*, through the tube *e*, which nearly reaches its bottom, so that after a few inches of water are poured in, no air can escape except by the tube *c*, up into the vessel *a*. The air will then be compressed by the weight of the column of water in the tube *e*, and therefore the force of the water from the jet pipe will be in proportion to the height of this tube. If this tube is twenty or thirty feet high, on turning the stop cock, a jet of water will spout from the pipe that will amuse and astonish those who have never before seen such an experiment."

Fig. 74.



(Art. 67.) The pressure of the air explains the action of the

SYPHON.

The syphon is nothing more than a tube bent in such a manner as to have two unequal branches, as represented by Fig. 75. If the tube be filled with water, and the shorter arm put into a vessel of water, the longer arm passing down over the side, and its end lower than the water in the vessel, water will run down the tube; because the weight of the water in the two arms are unequal, and the downward pressure in the longer arm is greater than the downward pressure in the other. But if water runs down the tube, there must be a tendency to form a vacuum

at the highest point, but the pressure of the air on the water in the vessel will not suffer a vacuum in the tube, unless it is more than 33 feet high: therefore, the highest point in the tube will be constantly full of water as long as there is a supply in the vessel, and of course it will constantly flow down the long arm until the water sinks below the extremity of the shorter arm in the vessel.

Fig. 75.

By the syphon we may empty wine and vinegar casks without disturbing their sediments, provided they are not in the lowest situation. The syphon may be used for draining marshes and ponds, by carrying the water over any elevation not exceeding 33 feet, provided the place of discharging is lower than the marsh or pond.

Water may be carried over a hill of less than 33 feet elevation to a house situated on a lower level; and in many instances this has been done. The only practical difficulty which presents itself, is how to fill the pipe with water so as to exclude the air, and thus start the operation. To accomplish this a trench is dug, the pipes are placed in it and soldered together; but, at the highest point, a funnel must be fitted, with a stop cock. When the pipes are thus laid, both ends must be stopped up and water carried to the highest point and the pipes filled through the funnel, and when filled, stopped air tight. Then the two ends may be opened, and the syphon will run as long as there is a supply of water at the fountain. Cellars may be drained in the same manner.

(Art. 68.) Before we close our observations on air and atmosphere, it may be proper to notice

WINDS.

Wind is air in motion. Whatever disturbs the equilibrium of the air, produces wind, and the variation of atmospheric pressure, and the variations of temperature, are two great causes, and perhaps the only causes, that produce wind.

The least change in temperature puts air in motion; air is expanded and rarified by the heat of a fire, and rises upwards, carrying the flame and smoke in the current, and the colder air rushes in to restore the equilibrium—and thus a fire can create an artificial wind on a small scale. From this cause a current of air is constantly ascending stove pipes and chimneys, carrying off the smoke and gasses of the consuming fuel, and, in common language, the pipes and chimneys are said to draw.

To secure a good draft to a chimney, the fire place should have a low front and narrow throat, so that all the air that may enter it should be warmed by the fire. *No more air should traverse the fire than what is necessary to support the combustion;* all that passes above that quantity serves only to cool the chimney and carry off heat. Stove pipes can rarely admit too much air, hence they draw much better than chimneys. The air of the apartment must be more dense than the air at the top of the chimney, otherwise the air will flow down, causing the room to smoke—which is frequently the case, and must be, in a close apartment and a chimney with a large throat.

When two places, not very remote from each other, have different degrees of temperature, the air will flow, or rather the wind will blow, from the colder region to the warmer.

This is illustrated by calling to mind the *land and sea breezes*, as they occur in hot climates. The land, during the day, being under the rays of a tropical sun, becomes heated in a greater degree than the surrounding ocean, and, consequently, there rises from the land a stream of warm air, during the day, while the cooler air from the surface of the water, moving forward to supply this partial vacancy, produces a cool breeze setting in upon the land.

During the night the motion of the air is reversed, because the earth, being heated superficially, soon cools when the sun is absent, while the water being warmed several feet below its surface, retains its heat longer.

Consequently, towards morning, the earth becomes colder than the water, and the air sinking down upon it,

seeks an equilibrium by flowing outwards, like rays from a center, and thus the *land breeze* is produced.

The wind then continues to blow from the land, until the equilibrium is restored, or until the morning sun makes the land of the same temperature as the water, when, for a time, there will be a dead calm. Then again the land becoming warmer than the water, the sea breeze returns as before, and thus the inhabitants of those sultry climates are constantly refreshed during the summer season, with alternate land and sea breezes.

The breezes tend to regulate the temperature and equalize the heat, and without them certain localities, which now enjoy a delightful climate, would hardly be inhabitable.

The trade winds in the Atlantic and Pacific oceans, are produced on the same principle as the land and sea breezes, only on a larger scale. The equatorial regions of the earth are more heated by the sun than other portions, and for that reason the general direction of the winds are towards the equator on both sides of it; and at the equator the opposing currents are so nearly equal in force and direction, that a very gentle breeze, or a dead calm, is produced, except on occasions of great storms.

These two currents towards the equator, start in latitudes where the motion of the earth eastward is less than at the equator: therefore, when they approach the equator, they do not move eastward as fast as that portion of the earth where they now are, and the effect is, that the earth is carried eastward against the wind, or the wind appears to blow from the north-east. For the same reasons the trade winds, south of the equator, blow from the south-east: at the equator they either directly meet and destroy each other, or meet with an inclination and make a very light eastern breeze. The currents of air thus constantly setting towards the equator, become more and more warmed by the perpendicular rays of the sun, and are supposed to rise up into the colder regions, and from thence flow toward the poles to restore the equilibrium.

Beyond the influence of the varying temperature, which produces the land and sea breezes, we have variable winds—beyond the limits of the trade winds which extend

to about thirty degrees each side of the equator, we have variable winds, or prevailing winds, which are maintained by local causes.

The north Atlantic ocean is warmer than the adjoining regions of the American continent, and this causes the prevailing *north-west winds* on the Nova Scotia and New England coast.

The winds on the eastern hemisphere are different from those on the western—owing to the different relative positions of land and water.

In winter the sun is over the Indian ocean, far away from the land: this draws the wind from the north. In summer the sun's rays heat the land on the north of the equator more than they heat the ocean, and this draws the wind from the south. These winds are called *the monsoons.* In the Indian ocean, about six degrees south of the equator—from the Island of Java nearly to the coast of Africa—a moderately gentle breeze is almost constantly blowing from the east. In latitude from 36° to 39° south, in the same ocean, a strong wind blows from the west, and often continues round New Holland. Hence, ships that sail for China in our winter season, when they would meet the north monsoons in the China sea, frequently go to the south of the Cape of Good Hope, take the west wind, go south of New Holland into the Pacific ocean, there take the trade winds to the equator, and thence make their way to the coast of China.

Ships from the North American coast, bound to Europe in the winter season, take a straight course to their port of destination; for they have reason to expect favorable winds. But ships bound from Europe to America expect heavy north-west gales from the coast, and for that reason they run down the European coast to the trade winds, with them cross the Atlantic in latitude about 27°, until they come to the longitude of about 70° west, and from thence they take a northerly course to their port of destination. Though the distance is much longer than the direct course, yet they would commonly arrive by it in less time, with far less wear and tear of the vessel, and with far less danger: and such circuitous voyages, which the intelligent mariner frequently takes, in

almost every sea, has given rise to the sailor's maxim, that—"The furthest way round is the surest way home."

Air and water, to a certain degree, have a chemical affinity—at least air always contains the vapor of water, and the more so in warm climates and in the vicinity of water. The warmer the air is, the more watery vapor it will hold; but in situations where no water is exposed to the air, such as on the Arabian deserts and on the great Sahara in Africa, the air is said to be painfully dry and parching: hence it absorbs the moisture from the eyes, lips and throat, and this has given rise to the idea of *poisonous winds*.

Air will hold more watery vapor in the warmth of day than in the cool of night: hence water drops are deposited from the air when the coolness of night draws on—and this is called *dew*.

When warm air, full of watery vapor, comes in contact with any cold substance—as a pitcher of cold water; on the outside of the pitcher will be seen drops of water deposited by the atmosphere in the manner of dew.

When cold air commingles with warmer air, especially when the latter is full of watery vapor, as the air generally is over lakes, streams, and rivers, a fog must ensue. A fog is partially condensed water vapor: when low and on the ground we call it fog, when high and above the ground we call it cloud.

Fog must form on rivers and streams in the cool of morning, after a warm and calm day; but, by the warmth of the sun, they are soon dispersed, if not blown away by the winds.

Fogs deposit small rain drops, which we call *mist*; but when the fogs are higher, and any considerable body of them, these drops accumulate and produce rain.

When warm air, full of watery papor, rises very high, and suddenly comes in contact with very cold air, we then have *hail*: hence, hail storms can rarely take place except in warm weather, for only then can warm air, attain any considerable elevation.

(Art. 69.) Before we close the subject of fluids, their mechanical properties and pressure, we must notice the

STEAM ENGINE.

It is impossible to represent this engine on paper with all its appendages and parts, nor is it necessary: all we shall attempt to do, is to show how the action of steam can be made to give motion to machinery; and we shall best accomplish this, by using the most simple drawings possible.

Fig. 76.

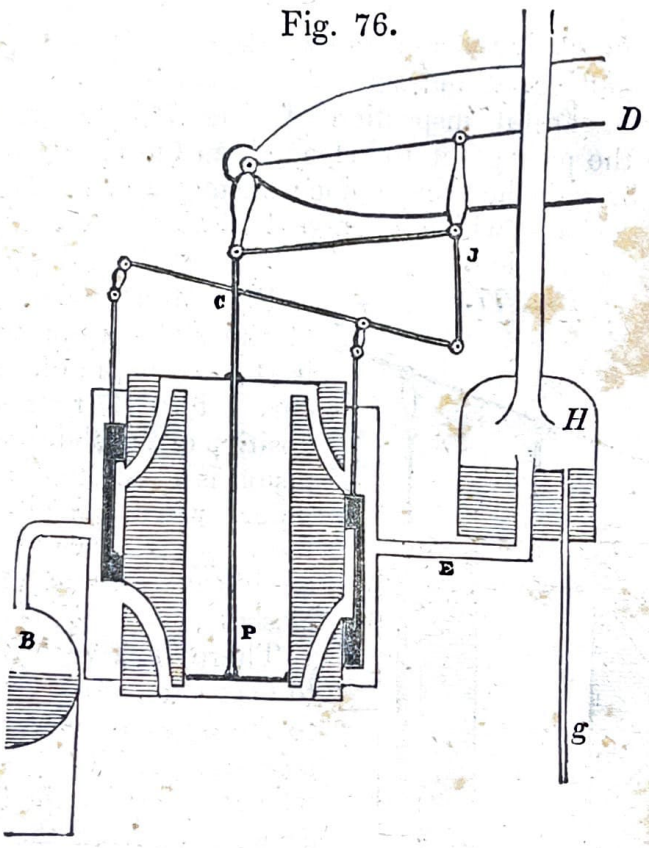


Fig. 76 represents an improved high pressure engine. *P* is the piston, which is worked up and down by the pressure of the steam. *B* is the boiler. The pipe from the boiler is called the steam pipe, and the pipe directly opposite, marked *E*, is called the eduction pipe, and passes into the vessel *H*, called the heater. From the heater passes the escape-pipe.

D is the centre of motion for the scale-beam, that is worked up and down by the piston; the other end works

a crank which turns a wheel not here represented. The motion of the scale-beam can work pumps. There are two pumps connected with the heater, (not here represented for the fear of confusion,) one to pump cold water into the heater, and the other to pump the hot water out and convey it to the boiler. If the cold water pump throws too much water into the heater, it runs out by the pipe *g*.

The escaping steam passing through the heater is partially condensed and heats the water.

By a careful inspection of Fig. 76, the reader can trace the passage of the steam from the boiler to its final exit through the escape-pipe; we may also see the motion of the *slides* which open and close the valves; *c* is a centre of motion.

Fig. 77.

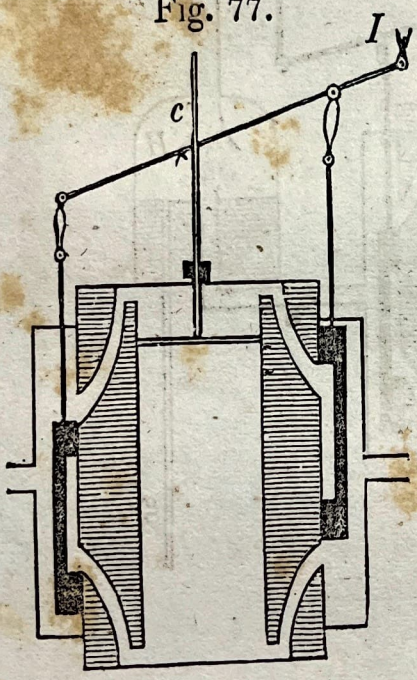


Fig. 76 shows the position of the slides when the piston is at the bottom of the cylinder. Fig. 77 represents the position of the slides, when the piston is at the top of the cylinder: when the piston is at the middle of the cylinder, for an instant all the valves are closed.

There is a variety of ways to open the valves, according to the fancy of the machinist; sometimes it is by an eccentric wheel attached to the fly wheel, as well as from the working beam as here represented.

To secure a uniform motion of the piston, there must *not* be a uniform pressure of the steam, *for a uniform force produces accelerated motion*, as we have seen in the investigation of falling bodies. Therefore, it will not answer to let the steam drive into the piston barrel through the entire ascent or descent of the piston, and the rod *I* can be attached to the scale-beam at any distance from the center of motion, so as to open and close the valves at any desired point. When the piston moves about one-

third of the way up or down, the valve which lets in steam should begin to close, and when the piston is in the center of the barrel both valves are closed, and the expansion of the steam already in the barrel finishes the stroke.

There are other parts of the engine not represented here, such as the boiler, the regulator or safety valve, &c., but they are all too simple in their construction to require illustration, and we close this article with the following vivid description by Dr. Arnot:

"The steam engine, in its present improved state, appears to be a thing almost endowed with intelligence. It regulates, with perfect accuracy and uniformity, the number of its strokes in a given time, and, moreover, counts or records them, to tell how much work it has done, as a clock records the beats of its pendulum. It regulates the supply of water to the boiler, the briskness of the fire, and the quantity of steam admitted to work; opens and shuts its valves with absolute precision; oils the joints; takes out any air which may accidentally enter into parts where a perfect vacuum is required; and when any thing goes wrong which it cannot of itself rectify, it warns its attendants by ringing a bell. Yet with all these talents and qualities, and even when possessing the power of 600 horses, it is obedient to the hand of a child. Its aliment is coal, wood, charcoal, or other combustibles; but it consumes none while idle. It never tires, and wants no sleep; it is not subject to any malady when originally well made, and only refuses to work when worn out with age. It is equally active in all climates, and will do work of any kind. It is a water pumper, a miner, a sailor, a cotton spinner, a weaver, a blacksmith, a miller; and a small engine, in the character of a steam pony, may be seen dragging after it, on a rail-road, a hundred tons of merchandise, or a regiment of soldiers, with greater speed than that of our fleetest coaches. It is the king of machines, and a permanent realization of the *genii* of eastern fable, whose supernatural powers were occasionally at the command of man."

CHAP. V.—ACOUSTICS—LAWS OF SOUND—WHISPERING GALLERY—DECEPTIVE SOUNDS—MUSICAL SOUNDS.

(Art. 70.) Acoustics is the science which treats of the nature and laws of sound, and includes the theory of musical concord and harmony. Sound is produced by the tremulous or vibrating motion of bodies. Bodies that cannot vibrate will produce no sound. Sound is communicated through the air to the drum of the ear, and thence to the brain.

If any sounding body of any considerable size is suspended in the air and struck, the tremulous motion is distinctly visible to the eye, and while the ear receives the sound, the eye may perceive the motion.

That sound is conveyed to the ear by the motion which the sounding body communicates to the air, is proved by an interesting experiment with the air pump. Among philosophical instruments, there is a small bell, the hammer of which is moved by a spring connected with clock-work, and which is made expressly for this experiment.

If this instrument be wound up, and placed under the receiver of an air pump, the sound of the bell may at first be heard to a considerable distance; but, as the air is exhausted, it becomes less and less audible, until no longer to be heard—the strokes of the hammer, though seen by the eye, producing no effect upon the ear. Upon allowing the air to return gradually, a faint sound is at first heard, which becomes louder and louder, until as much air is admitted as was withdrawn.

From this we infer at once, that the more dense the atmosphere, the greater or more forcibly all sounds will strike the ear,—and this fact has been frequently tested.

Persons high up on a mountain, where the air is very much rarified, can hardly hear each other speak, and the sound of a musket, in such situations, is said to be no greater than the common sound of a pop-gun.

At night sounds can be heard much farther and much more distinct than in the day time—some say it is because the atmosphere is more dense, others say that

it is because all the confusing sounds of animals and insects in the night are silent. Neither solution, nor both together, seem quite adequate to account for the great difference said to exist. Humboldt said, that the noise of the great cataract of Oronow, which he described, was three times greater in the night than in the day.

The distance to which sounds may be heard, will of course vary with their force, the state of the air, and the various other circumstances which are incapable of being numerically estimated.

Volcanoes, in South America, have been heard at the distance of three hundred miles, and naval engagements have been heard at near two hundred miles. Under the most favorable circumstances, the unassisted human voice has been heard from Old to New Gibraltar, a distance of about ten miles,—the watch word, *All's well*, given at the former place, has been heard at the latter. Sounds are heard much farther over still water than over land; and much farther over smooth and hard ground than over a rough and broken country.

(Art. 71.) Sounds move through the air, in a similar manner as waves on still water: they generally spread in all directions—but they can be propelled more in one direction than in another and may be interrupted by intervening obstacles.

A cannon makes a much louder report to a person stationed any distance before it, than it does to another stationed the same distance behind it. It is difficult to hear a public speaker at any considerable distance, unless we are before him. A bell will throw its sound much farther in the direction it swings than in the cross direction, and this should be considered when a new bell is about to be suspended.

(Art. 72.) *The vibrations of a sounding body continue for a longer or a shorter time, according as the body is more or less elastic, or as it is thicker or thinner.* Any one may satisfy himself of this fact, by a very rude experiment—that of striking a barrel when empty and when filled; or snapping a long and a short string drawn over a box.

(Art. 73.) The air is the most common medium to conduct sound, but it is not the only medium,—various other

bodies, both liquid and solid, are excellent conductors of sound, but sound suffers much diminution from passing from one medium into another. If a log of wood is scratched with a pin at one extremity, and the ear applied to the other, the sound will be distinctly heard; but it cannot be heard at even a small distance from the log.

If a watch be attached to one end of a long elastic pole, and the other end taken between the teeth, the ticking of the watch can be distinctly heard, but could not be heard the same distance through the medium of the air. The motion of a troop of horse may be heard much sooner by placing the ear to the ground, than by standing erect;—in this way Indians and animals listen for distant and expected sounds.

A train of cars may be heard a long distance, by putting the ear close to the rails—especially when the road is solid and well made.

(Art. 74.) "*The velocity of sound is progressive.* Thus, when a gun is fired at a distance from us, we perceive the flash some time before we hear the report. Thunder follows the lightning at a perceptible interval, although they are known to be cotemporaneous events. If a gun be fired at a certain known distance, and we observe the interval between the flash and the report, we may obtain the rate at which sound passes, that is, the velocity of sound. Many years since, Dr. Derham made a number of accurate and diversified experiments on this subject, and fixed the velocity of sound at 1142 feet per second."

It is the same for all kinds of sounds: the sound of a cannon and the softest whisper have been found to move with equal velocity. But it is not always 1142 feet; many experiments have given it at 1130.

Since, however, the transmission of sound depends on the elasticity of the medium, causes which affect the elasticity likewise affect the velocity of sound. Thus, the velocity is a little greater in warm than in cold air, and consequently is somewhat influenced by climate.

(Art. 75.) It is natural to suppose, that sound would move most rapidly when first created, and more slowly as the sound dies away—but such is found not to be the fact.

Sound moves with a uniform velocity; that is, it passes over equal spaces in equal times. This important fact was first ascertained by Derham, who found that it held good whether the sound was strong or feeble, whether it proceeded from a hammer or a cannon: in short, that neither the strength nor the origin of the sound made any difference. M. Biot caused several airs to be played on a flute at the end of an iron pipe 3120 feet long, and the notes were distinctly heard by him at the other end, without the slightest derangement in the order or quality of the sounds. The velocity of sound, however, when transmitted, through the air, is slightly influenced by the strength and direction of the *wind.* Dr. Derham found that when the wind is blowing in the direction of the sound, its velocity must be added to the standard velocity of sound, and must be subtracted from it when opposed to it. A *transverse* wind does not affect the velocity of sound in the slightest degree.

"The velocity of sound has been applied to the measurement of distances.

1. A ship at sea in distress fires a gun, the light of which is seen on shore 20 seconds before the report is heard; therefore it is known to be at the distance of 20 times 1142 feet, or little more than $4\frac{1}{2}$ miles.

2. I see a vivid flash of lightning, and if in three seconds I hear a tremendous clap of thunder, I instantly know that the thunder-cloud is only two-thirds of a mile distant; I should, therefore, retire instantly from any exposed situation.

3. The pulse of a healthy person beats about seventy-six times in a minute; if, therefore, between the flash of lightning and the thunder, I can feel 1, 2, 3, 4, &c., beats of my pulse, I know the cloud is 900, 1800, 2700, 3600, feet from me. A still better method is by a watch having a second hand."

(Art. 76.) Solid substances convey sound not only better, but much quicker than the air—as has been proved by the following experiment of M. Biot at Paris:

A train of iron pipes were laid to convey water to the city (about 3000 feet.) A ring of metal was placed against the tube and a small bell within it, so as not to

touch the tube; both the ring and the bell were struck at the same instant; the sound of the ring was conveyed along the tube, the sound of the bell through the air within the tube, and the result was that the sound of the ring was heard at the other end much before the sound of the bell; and, by the means of several experiments, it was decided that the metal conducted the sound at the rate of about 11,865 feet per second, *which is more than ten times the velocity through the air.*

"The great power of solid bodies to conduct sound is exemplified in *earthquakes*, which are heard almost simultaneously in very distant parts of the earth. It is easy to ascertain whether a kettle boils, by putting one end of a stick or poker on the lid, and the other end to the ear: the bubbling of the water, when it boils, appears louder than the rattling of a carriage in the street. A slight blow given to the poker, of which one end is held to the ear, produces a sound which is even painfully loud."

Prof. Olmstead says, that "a physician of Paris introduced into medical practice an instrument, depending on the power of solid bodies to conduct sound, called the *Stethoscope*, the object of which is to render audible the actions of the heart and the neighboring organs. It consists of a wooden cylinder, one end of which is applied firmly to the breast, while the other end is brought to the ear. By this means, the processes that are going on in the organs of respiration, and in the large blood vessels about the heart, may be distinctly heard; and it is said that the stethoscope, when skilfully used, 'becomes the means of ascertaining some diseases in the chest, almost as effectually as if there were convenient windows for visual inspection.'"

(Art. 77.) Sound, like material bodies, (Art. 16,) is capable of being reflected by hard bodies and plane surfaces, and this reflection of sound is sometimes called an *echo.*

As in material bodies, when sound strikes against any surface, *the angle of incident is equal to the angle of reflection.*

The surfaces of liquids and fluids are capable of reflecting sound as well as solid bodies. The bottom of a well, and even the clouds, have been known to return sounds.

The rolling of thunder is sometimes the result of echoes among the clouds, as we infer from observation on the sound of cannon. The discharge of a cannon under a clear sky, gives but one sharp and single report; but, when the clouds are above and around, the report is followed by a continued roll like thunder, or by more distant echoes.

But, says Prof. Olmstead:

"The continued sound of distant thunder, which is sometimes prolonged for many seconds, is not always owing to reverberation, but frequently arises simply from the different distances of the same flash. Although the progress of a flash of lightning through the air were absolutely instantaneous, still, if its path were in a line that would carry it farther from the ear in one place than in another, there would be a corresponding difference in the times at which the sound generated in different portions of the path would reach the ear. Herschel observes, that if (as is almost always the case) the flash be zigzag, and composed of broken, rectilinear, and curvilinear portions, some concave, some convex to the ear; and especially, if the principal trunk separates into many branches, each breaking its own way through the air, and each becoming a separate source of thunder, all the varieties of that awful sound are easily accounted for."

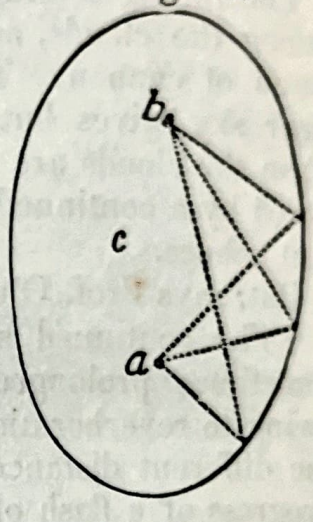
A cannon discharged in a valley among mountains generally returns several echoes, seemingly as though other cannon were fired around among the mountains. The report of cannon, and all other sounds, give no echoes at sea, or in a plane level country, because there is nothing to impede and reflect the sound.

(Art. 78.) If a person should stand in the center of a circular room: the sound of his voice passing in right lines to the sides of the room would be reflected back to the same point, and the echo would be nearly as loud as the original sound,—indeed it might go and return several times, fainter and fainter each time.

If a room be made in the shape of *an ellipse*, as represented in the adjoining figure, (Fig. 79,) then all sounds originating at *a* will pass in straight lines to the

sides of the room, and be reflected to *b*, or if they originate at *b*, they will all strike the sides of the room and be reflected to *a*. The points *a* and *b* are termed focii of the *ellipse*, and one essential property of the ellipse is that all lines drawn from one focus to the side of the ellipse, and from thence to the other focus, the line will make equal angles with the *curve* or side of the room; and as the angle of incidence must be equal to that of reflection, therefore *sound must be reflected from one focus to the other.*

Fig. 79.



Galleries in this shape are called *whispering galleries*, for two persons can place themselves, one at one focus, the other at the other, and whisper to each other with perfect distinctness, but a third person intermediate between the two can hear nothing, nor can a person hear the whisper at any other locality, for suppose a person placed at *c*, he will receive only one ray of sound from *a* while the person placed at the focus *b* will receive not only the direct rays from *a*, but all the reflected rays from all sides of the room.

Great secrets are said to have been discovered by placing prisoners and suspected persons at one focus of such a gallery, and a listener at the other. When the prisoners or suspected persons were not philosophers, and unaware of their position and the concentration of sound in the room, might naturally and inadvertently converse with each other, and if they did so, the listener, though sufficiently far to dispel all suspicion and banish all caution, would hear every word.

The audience rooms of theatres are generally constructed after the form of a whispering gallery,—that is, in the shape of an *ellipse* of greater or less eccentricity; the front of the stage where the speakers generally stand is one focus, and the front of the central box is the other, or near the other. All assembly rooms, large lecture rooms, and churches, should conform to this principle, and where we see a large hall or church room with very

high ceiling, square corners, corner recesses, &c. we have reason to suspect that the directors and the architect had neglected or forgotten their lessons in *acoustics*.*

(Art. 79.) We judge of the direction which sound comes, something as we judge of the direction which the wind blows. The vibrations of the air are in a certain direction, and they commonly strike one ear stronger and quicker than the other, and when this is the case, there can be no doubt as to the direction from which the sound proceeds, and there can be no deception, unless the sound which meets our ears is a reflected sound, and the direct vibrations are cut off by intervening objects.

When sound (or the atmospherical vibrations of the air caused by sound) are feeble and strike both ears alike, we are not certain as to the direction of the sound, and we naturally look in all directions for its origin.

Our hopes, fears, expectations, and imaginations have much to do with locating sound, or these external circumstances may cause great *deceptions*.

If a person is in a strange wood in a single path, and hears the sound of a human voice, or the tramp of a horse, but sees neither man nor horse, he will immediately look behind him in the pathway, conceiving the sound in the path, because he would naturally expect it to be there, although it might actually be in quite another direction.

If a person is sitting in a room expecting a wagon from any particular direction, and is listening for the sound,—the sound of a wagon comes, and to the listener's ear it is from the direction expected, but it may really turn out to be an unexpected vehicle from the very opposite direction.

A person in sight of a dwelling, and indistinctly hearing the sounds of children or domestic animals, will immediately conceive the sounds as originating at the house, or from about the house, because that is the usual place from which such sounds emenate, yet upon examination he may find that they come to him from quite a different direction. The author of this work has been very sensibly struck with these facts during his wanderings in the semi-barba-

* A foreign traveller, after observing many of our theatres and churches, remarked that in the United States the "DEVIL had all the science." The theatres were constructed in conformity to the law of acoustics, while the churches seemed to pay no attention to it.

rous countries of the East, where the wealthy entirely enclose their dwellings by high and close walls so as to entirely exclude them from view, and the entire stranger is quite ignorant of dwellings being there, unless a gate-way is open. On the opposite side of the way from such habitations are commonly several huts where the poor and destitute reside.

The stranger passing along hears the sounds of dogs and children in high-toned glee and noisy tumult, very distinct and clear, and he looks at the huts for a sight of the dogs and children, for he is sure they must be there, but he sees them not, and he thinks it strange. The sounds continue, becoming more loud and clear, and what was strange a few moments before is now mysterious; but all of a sudden the passing stranger comes opposite to an open gate in the high and uncouth wall, and within he sees both children and dogs, and the first moment thinks it very singular that he should be so mistaken as to the locality of the sounds,—but in such instances there is really no mystery, for the sounds must pass through the gate-way, and from thence undulate through the air in all directions, and by a very little help of the imagination, the hearer must conceive the sounds as coming from the huts on the opposite side of the way.

Persons residing in a large building, as a hotel or college hall, may know that Mr. A., a flute player, resides in a particular room, and they frequently hear the sound of his flute in that particular locality. One evening, unlike his usual custom, he plays in a neighboring room, and all the hearers who are not acquainted with the absolute fact, would be ready to take oath that they heard Mr. A. play the flute in his room at such a time, and that they could not be mistaken.

The occupants of a certain room in a boarding house or college, may not be as quiet and orderly as they should be, and, in short, by unnecessary turbulence, the room has acquired a bad name;—after this, the unexpected and occasional tumult of neighboring rooms, (could we suppose tumult to occur,) would be immediately charged to the room having the *bad name*, because the mind of the hearer is thrown to that locality before his ear has time to adjust and discriminate between sounds.

Here then is the reason why the guilty must bear more than their real share of guilt, and why the wicked "flee when no man pursueth," for they are in a condition to expect pursuit, and that alone is sufficient in some instances, to hear the footsteps of a pursuer, when the sound that caused it is no more than the throbs of conscience moving stronger pulsations of the heart.

A very timid and superstitious person, alone at night, expects, or rather fears, that he will see a supernatural being; his imagination is worked up, and his nerves are all attuned in harmony with his fearful expectations, and should any real sounds and sights occur, it would be wonderful if they were not to his mind, the voice and appearance of the expected ghost.

(Art. 80.) The *ventriloquist* is a person who has most perfect organs of voice, has a very delicate ear to distinguish the variety and different degrees of sound, and power to imitate them. Then with a correct knowledge of the facts, how far the imaginations and expectations of persons modify sounds to their ears, his art becomes complete.

The chief essential to make a ventriloquist is to have the power of making various sounds without moving the lips or muscles of the face,* or to move them so quick and slightly that others may not perceive the motion or change of feature, but as this is impossible when one is closely observed, the actor commonly takes the precaution to have a screen that he can conceal himself from view as occasion may require.

He is careful, also, to lead the expectations of his audience to expect certain sounds before the sounds come; for instance, the ventriloquist is very fond of exposing a drunken man in a cellar, who has gone down to draw his beer and cider, bumped his head or broke his pitcher, for such sounds are coarse, uncouth, and easily imitated, and noise from below, from any confined place, has a peculiar sound, which, if successfully imitated, will master the imaginations of the hearers.

The operator in this art may go to the window, and say that he observes neighbor Smith's pig in the garden, and

* The literal meaning of the word ventriloquism is belly talking,—more genteely, talking within the chest and not with the mouth.

he will call the dog and drive him out, but Mr. Smith is a crusty old fellow who may stone the dog and become very angry.

Now the audience is prepared to hear all the different sounds attendant on such a scene. The ventriloquist opens the window, and in his natural voice calls a dog—then apparently as at a great distance, the yelping of a dog is heard; the sound becomes louder and louder, and now the pig begins to squeal, quite furiously;—finally, a low and indistinct sound of *get out* is heard from Mr. Smith at a distance, but he soon comes near, and vents his passion in no measured terms; a stone is heard striking the fence, the dog changes his tone from a bark to the cry of pain, and the window closes and closes the scene.

We are here strongly tempted to relate some amusing rogueries of ventriloquists, but they would be rather inappropriate in a work like this. We therefore pass on to

MUSICAL SOUNDS.

(Art. 81.) Musical sounds are not essentially different from other sounds, except *regularity* and *harmony* as to time, as we may ourselves conceive by the following consideration. Let a boy strike on a board with a stick and it makes only a *noise*, but let him strike quickly, uniformly and regularly, and the noise is not quite so irksome or annoying. Now let him take two sticks and strike in proper and regular succession,—in short, let him *drum*, and in place of *noise*, it is now *music*.

A cord drawn over a box of thin and elastic sides, when struck, produces musical sounds, because the vibration of the cord, and also of the sides of the box, are *quick* and *uniform*, and these are the principal requisites for music.

Two strings of *equal length*, *tension*, *and thickness*, will sound the same note, or be in unison. Two pipes of the same length and diameter will agree in the same manner. Large instruments and long strings produce grave and deep tones; small instruments and short strings produce acute or high tones.

In the case of the strings, the air is struck by the body, and the sound is excited by the vibrations; in that of the pipes the body is struck by the air, but as action and reaction are equal, the effect is the same.

Let a musical string of any length be divided into two equal parts by a bridge in the middle; and the sound of each half is eight notes, or an octave higher than the tone of the whole string.

Organ-pipes produce grave or acute tones in proportion to their length and size. It is the shortest string of a harpsichord or piano-forte which yields the highest notes.

The natives of Sumatra and Java make a rude musical instrument. It is a box very nearly in the shape of a coffin, and sticks of very hard elastic wood are fastened across it near the top; the largest and longest pieces give the gravest tones, and the shorter and shorter, the more acute tones. They strike along on these sticks with a little wooden hammer, and the sounds are far from being unpleasant. Several hundred of these musicians will sometimes get together, each playing independently by himself, and if the music is deficient in quality it is made up in quantity, for the sound can be heard for many miles. In more refined society, where music is cultivated as a science, great attention is paid to secure perfect harmony and concord among different players, and the master of music has an exquisitely delicate ear to detect discordant sounds. It is said that a master of the band of the king of Naples had such a delicate ear, that among thirty different players, all playing on different instruments, he could not only detect a discordant note, but the instrument that made it.

(Art. 82.) Speaking trumpets and long tubes are made to confine the vibrations in one direction, or convey the sounds to a particular place. When we stand behind the person who uses the speaking trumpet, we hear only a confused noise; when in the line along which the trumpet is directed, the sounds are much louder and more distinct, than the unassisted voice could make; for this reason they are used on shipboard, and among the apparent confusion of fire companies, when it is necessary to convey orders to a considerable distance through a multitude of other sounds.

Sounding pipes are very long speaking trumpets extending from the speaker, to, or near to, the hearer, such as from the upper story of a large building to a lower story; from the upper deck of a steam boat to the lower deck, by which the pilot and engineer can converse with perfect ease, though separated by considerable space, amid confusion.

SECTION IV.

CHAPTER I.—OPTICS.—UNCERTAIN NATURE OF LIGHT—LINES OF LIGHT—VELOCITY OF LIGHT—OBJECTIONS TO THE THEORY OF EMANATIONS—INTENSITY OF LIGHT.

(Art. 83.) This branch of natural philosophy treats of light and the laws of vision.

We are ignorant of the nature of light, although every body knows what we mean when the word is mentioned.

Two theories have been given to explain the phenomena of light. According to one, light consists of a great number of particles of matter, emanating from luminous bodies in all directions, and that these particles are exceedingly small. According to the other, all space is filled with a fluid incomparably more rare than the air or any other fluid, and which is denominated a *luminous ether*, and that the undulating motion in this fluid produces in us the sensation of vision, as sound is transmitted through the air, or waves over the surface of water.

The theory of emanation is the oldest, and has been the most universal, but the theory of undulation is now fast gaining ground.

We shall advocate neither theory, because we are not able to decide even for ourselves which is true, and either will explain all the facts with which we are acquainted; our *language* however will correspond to the theory of emanation, as that more readily corresponds with our habits of thought.

The following technicalities will be employed:

Without light we would perceive no object, hence light is that principle or substance which enables us to see things. Its nature cannot be defined.

Luminous bodies are such as emit light from their own substances, or *cause* the undulation of that something we call light. Hence, the sun, a lamp, fire, and phosphorus, are luminous bodies. The moon and planets, like the shining roof of a house or the bright dome of a cathedral, throw off or *reflect* the sun's light, and they are not of themselves luminous bodies.

Transparent bodies permit light to pass through them, such as glass, air, water, &c

Opaque bodies do not permit light to pass through them.

Translucent bodies permit some light to pass through them, but not enough to render objects visible.

Illuminated, enlightened. Any thing is illuminated when the light shines upon it, so as to make it visible. Every object exposed to the sun is illuminated. A lamp illuminates a room, and every thing in it.

A *Ray* is a single line of light, as it comes from a luminous body.

A *Beam* of light is a body of parallel rays.

A *Pencil* of light is a body of diverging or converging rays.

Divergent rays, are such as come from a point, and continually separate wider apart, as they proceed.

Convergent rays are those which approach each other, so as to meet at a common point.

Luminous bodies emit rays, or pencils of light, in every direction, so that the space through which they are visible is filled with them at every possible point.

The point from which diverging rays proceed, is called the *radiant point;* that to which converging rays are directed, is called the *focus.* A ray of light, bent from a straight course in the same medium, is said to be *inflected;* when turned back on the surface of a body, it is said to be *reflected;* and, when turned out of its course as in passing out of one medium into another, it is said to be *refracted.*

(Art. 84.) Light moves in straight lines, as we infer from the following observations:

1. Rays of light will not pass through a bended tube.

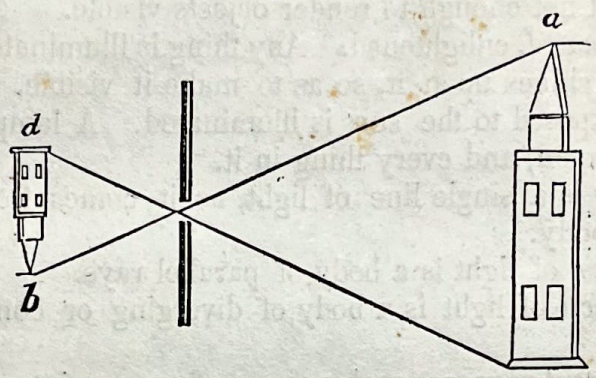
2. Rays of light passing through a small orifice into a dark room proceed in straight lines.

3. The lines bounding the shadow of any object are in direct lines from the luminous body.

One curious result of the rays of light moving in right lines, may be observed in a darkened room, with one small aperture, (such as an auger hole in a close shutter.) The image of any bright or illuminated object in front of the aperture may be seen on the opposite wall in an inverted position.

The image will appear, if the external object has sufficient light, and the reason of its being inverted will be perfectly obvious by inspecting

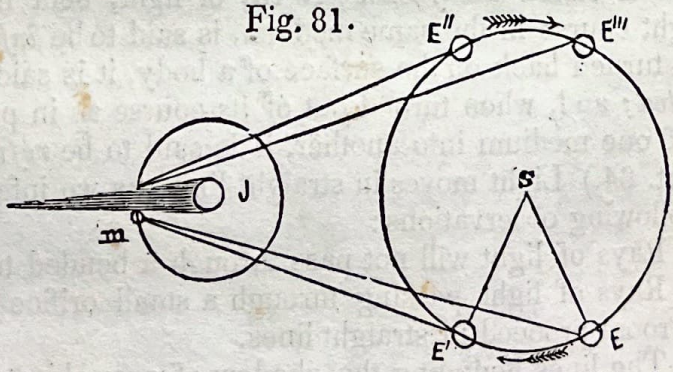
Fig. 80.



(Art. 85.) *Light is progressive, and its velocity is about* 192.000 *miles per second.*

This velocity is so great that for all practical purposes on the surface of the earth, it may be considered *instantaneous.* And it is at once evident that this fact could not have been discovered by any terrestrial observations,—in short, it must have been some observations in celestial space. It was by repeated observations on the eclipses of Jupiter's first satellite, as we shall now attempt to explain.

Fig. 81.



In (Figure 81,) let *S* represent the Sun, *J* Jupiter, *E* Earth, and *m* Jupiter's first satellite. By careful and accurate observations astronomers have decided that the mean revolution of this satellite round its primary is performed in 42 hours 28 minutes and 35 seconds; that is, the mean time from one eclipse to another.

But when the earth is at *E* and moving in a direction towards, or nearly towards, the planet as represented in

the figure, the mean time between two consecutive eclipses is shortened about 15 seconds, and we can explain this on no other hypothesis than that the earth has advanced and met the successive progression of light. When the earth is in position as respects the Sun and Jupiter as represented in our figure at *E* and moving from Jupiter, then the interval between two consecutive eclipses of Jupiter's first satellite is prolonged or increased about 15 seconds.

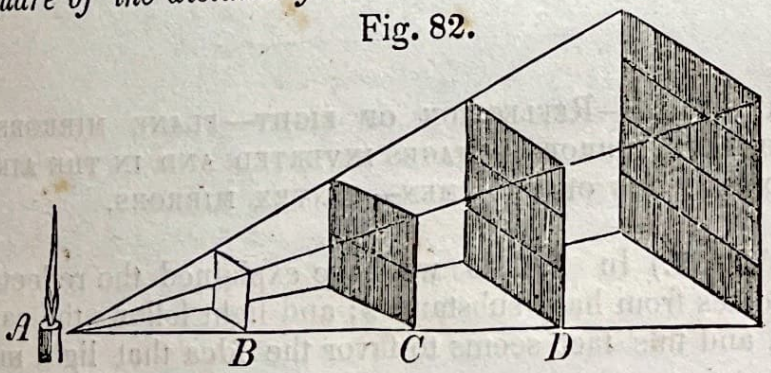
But during the interval of one revolution of Jupiter's first satellite, the earth moves in its orbit about 2,880,000 miles, this divided by 15 gives 192,000 miles for the motion of light in one second of time—and this velocity will carry light from the sun to the earth in about 8¼ minutes.

(Art. 86.) Now if light is a real substance emanating from a luminous body, its extreme velocity would give it great momentum, which must become apparent by its effects, but as no such effects are known, it is a serious objection to the theory of emanations. In this particular it is far more rational to suppose that light every where exists in celestial space as an electric fluid, and is caused to undulate or vibrate like a wave by the pressure or action of a luminous body.

This latter theory of light may give us an idea of our being able to see through solids, such as water, glass, &c. If light consists of particles, and passes from the luminous body as from the sun or a lamp, it is difficult to conceive that those particles pass through solid glass and other close substances, but with the latter theory light may be self-existent in glass, and in all other substances that we can see through.

(Art. 87.) *The intensity of light varies inversely as the square of the distance from the luminous body.*

Fig. 82.



This is illustrated as follows:—Let *A* (Fig. 82,) represent a light and *B* an aperture in a piece of paper, through which the rays of light pass from the point *A*. Place *C* twice as far from *A* as *B* is from *A*, and the same rays of light that pass through *B* are spread equally over the surface of *C*. But the surface of *C* is four times that of *B*; hence the light on the same surface at the distance of *C* is $\frac{1}{4}$ what it would be at the distance of *B*. If the surface to receive the light is placed at *D*, three times the distance of *B*, the same light that passes through *B* is spread over 9 spaces, each equal to *B*, therefore on one such space there is only $\frac{1}{9}$ of the light that passed through *B*.

In a similar manner we perceive that if the distances from the light are represented by the numbers 1, 2, 3, 4, &c. the intensities of light must be 1 $\frac{1}{4}$ $\frac{1}{9}$ $\frac{1}{16}$ &c. the latter series of numbers being the inverse squares of the former.

(Art. 88.) Whether light emanates from a point, or undulates as in waves, the lines of emanation or undulation are straight in the same medium. But when they pass from one medium to another, as from the air to water, or to glass, the lines are bent downwards into the denser medium, and this bending is called refraction.

Smooth and bright substances which do not permit light to pass through them throw it off, the same as hard surfaces throw off material and elastic bodies, (Art. 16,) and this throwing off is called *reflection of light*, and nearly the whole science of optics, and the whole philosophy and investigation of optical instruments is comprised in the subjects of *reflection* and *refraction* of light, which will be explained in the following chapter.

Chapter II.—Reflection of light—plane mirrors—concave mirrors—images inverted and in the air—exhibitions of showmen—convex mirrors.

(Art. 89.) In Art. 16 we have explained the reflection of bodies from hard substances; and light follows the same law, and this fact seems to favor the idea that light must

be a material substance emanating from luminous bodies. All visible substances that are not luminous, reflect more or less light, or they could not be visible, and in this sense all substances may be called *reflectors*, but it is not in this sense that we shall use the term *reflector*.

A *speculum* or *mirror* may be made either of metal or glass, if the surface is highly polished. When made of glass they are quicksilvered on the back to make them reflect more light, and these reflectors are most commonly called mirrers.

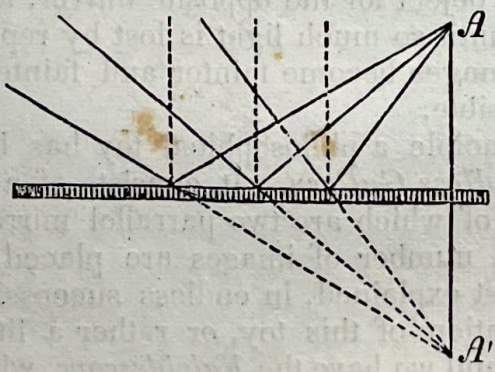
When reflectors are made of metal, such as silver, steel, &c. the term *speculum* is mostly applied.

Mirrors may be either *plane*, *convex*, or *concave*.

The common looking-glass is a plane mirror, and all rays of light that strike it (or any other plane mirror), *the angle of incident is equal to the angle of reflection.* (See Art. 16.)

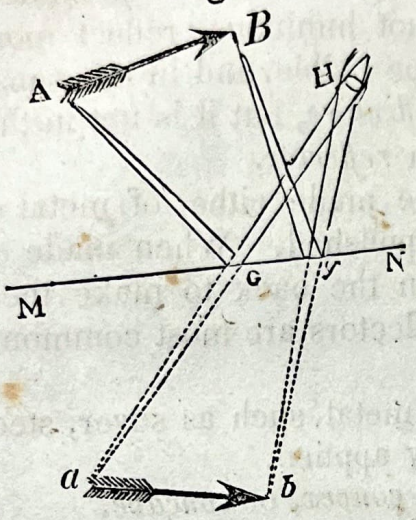
(Art. 90.) On this principle, when any rays of light fall from any object on a plane mirror, each single ray will incline to the surface of the mirror the same after reflection as before. And when rays *diverge* from any point *before* the mirror, the *reflected* rays from the mirror are in the same lines as though the rays come from a point which is just as far *behind* the mirror as the object or point is before the mirror. This must be apparent from Fig. 83. *A* is the object before the mirror, and *A'* is the image behind the mirror.

Fig. 83.



For further illustration that images are as far behind the mirror as the objects are before it, we give Fig. 84.

Fig. 84.



Let *MN* be a plane mirror, and the arrow *AB* represent any object before it. The eye situated any where in front of the mirror, so as to receive some of the innumerable rays of light that reflect from the mirror. To avoid confusion, the figure represents only two lines of light from each extremity of the object, and as the eye is not a mere point, more rays than one from each extremity can enter the eye, but these reflected rays enter the eye as though they came from a point which is as far behind the mirror as the object is before it, (Fig. 83,) and thus our figure shows the image of each extremity of the object as far behind the mirror as the real extremities are before it,—and this is true of any and every point of the object—that is, the image of the entire object is as far behind the mirror as the object is before it.

(Art. 91.) *When an object is placed between two parallel plane mirrors, a succession of images are found in each mirror at equal distances behind each mirror.*

Conceive two large mirrors against opposite sides of a small room, and a person standing between them, he will see his own image in each mirror,—and each image will now be a new object for the opposite mirror, and so on indefinitely, or until so much light is lost by repeated reflection that the images become fainter and fainter, until they cease to be visible.

On this principle a philosophical toy has been formed called the *Endless Gallery*. It consists of a box, in the opposite sides of which are two parrallel mirrors, and between them, a number of images are placed, which are repeated as just explained, in endless succession.

A little variation of this toy, or rather a little improvement upon it, and we have the *Kaleidescope*, which consists of either two or three plane mirrors placed in a tube running lengthwise and inclined to each other at an angle of

60°. At one end of the tube is an arrangement or space to hold small objects, such as colored beads, pieces of glass, &c. and at the other end there is a cap with a small aperture. On placing the eye to this aperture, the images of these objects are seen reflected in endless succession from mirror to mirror, forming a beautiful hexagonal combination, and by turning the tube a new order of the objects is formed, and of course new reflections to a never ending variety.

(Art. 92.) As all rays of light are reflected from a plane *mirror* with the same inclination that they meet it, it follows that any object must be correctly represented by reflection, and if not correctly represented, it shows that the mirror is not *plane*, or has not a plane surface, and in this consists the goodness or worthlessness of a mirror.

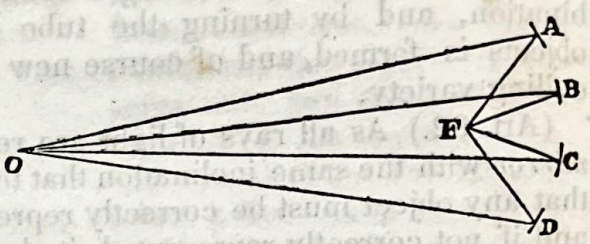
To try a mirror, hold a straight rod before it and observe if its image is straight, or hold a lighted taper before it and see if it will any where show two lights. A mirror may be quite perfect when purchased, but after a while being exposed to heat and cold, moist and dry air, becomes warped, and of course faulty. It is very difficult to obtain perfect mirrors, and the more so as they are larger, hence a large perfect mirror demands a high price.

(Art. 93.) When a plane mirror is changed in position, or turns on an axis, *the image revolves twice as fast as the mirror*. This is in consequence of the angle of incident being equal to the angle of reflection, and it is made manifest by placing a mirror at an angle of 45° with the horizon; this will throw the image of a *vertical* object into a horizontal position. Now if we gradually raise the lower side of the mirror until it attains a horizontal position, the image will rise from the horizontal all the way to the vertical; that is, by moving the mirror 45° the image revolves 90°. On this principle, instruments are made for measuring angles by reflection. A mirror is adjusted to an index bar, and turns on the plane of a *circle*, on which circle half degrees are marked as whole ones. These instruments are used at sea to find latitude and longitude, and are known as Hadley's Quadrant, which has been improved into the *Sextant* and astronomical circle.

CONCAVE MIRRORS.

(Art. 94.) Whatever be the general shape of a mirror, the point where any ray of light may strike it, may be considered as a point in a plane *mirror*, and *the angle of incident equal to the angle of reflection.*

Fig. 85.



The action of a concave mirror may be easily understood by considering it as made up of several plane mirrors, *A*, *B*, *C*, *D*, &c. (Fig. 85.) *O* an object, from which rays of light fall on each of the plane mirrors, *A*, *B*, *C*, &c. and by the position of the mirrors and law of reflection, the reflected rays must meet in a point *F*. This point is called the *focus*.

When many rays of light meet at any one point, they must form an image of the object from which the light flows at that point, *provided there is any thing, even air, to interrupt the reflected* rays of light and render them visible.

A regular concave mirror, in a mathematical sense, is a portion of a sphere; a line passing through the center of the sphere and to the center of the mirror is called the axis. Rays of light passing from any object parallel to the axis are called parallel rays. Rays of light passing from a point into the mirror, as represented by Fig. 82, make diverging rays. Rays of light coming from any object larger than the mirror, give converging rays.

The focus for parallel rays is half way between the center of the sphere and the mirror.

The focus for diverging rays is farther from the mirror.

The focus for converging rays is nearer the mirror.

Figures 86 and 87 represent concave mirrors. *MN* a very small section of the mirror. *A* the radiating point. *F* the focus, and *C* the center of the sphere.

If *aM* and *aN*, as in Fig. 86 converge towards the mirror, the point *A'* will be behind the mirror, and the focus *f* will be nearer the mirror than the focus for parallel rays, which is at *F*, half way between the center of the sphere and the mirror.

Fig. 86.

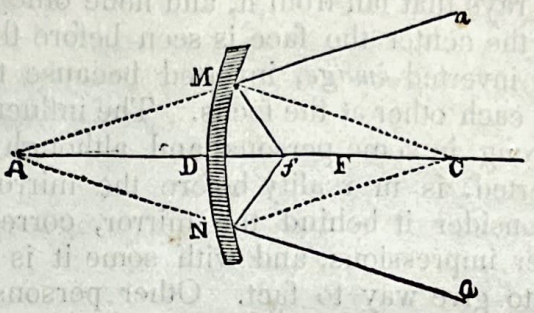
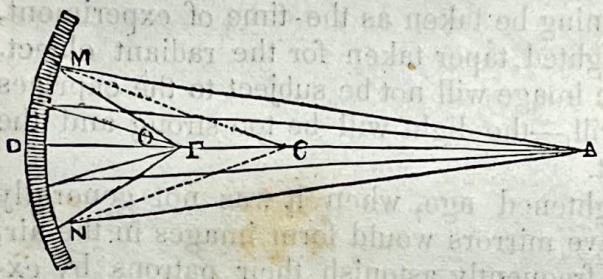


Fig. 87.



In Fig. 87 if we conceive the object to be at *F* instead of *A*, *FM*, *FN*, &c. will be the direct rays, and *MA*, *MN*, &c. the reflected rays, and these rays must meet at *A*, and there form an image of the object. From this relative interchange between the radiant points and the foci, the points *F* and *A* have been called *conjugate* foci, because either one may be the radiant point or place of the object, the other will be the *focal point* or place of the *image*.

If we place an object at *f* Fig. 86 the reflected rays will diverge after reflection, and of course form no image before the mirror, but will converge behind the mirror and form an *image* at *A'*. But this image at *A'* being farther behind the mirror than the object is before it, will be larger in that proportion.

When a person looks into a concave mirror, he may notice the following phenomena:

When the mirror is very near his face, he sees his image *distinct* and enlarged. If he then gradually withdraws his eye, the image grows larger, until the eye reaches the focus for parallel rays. From the focus to the center of the sphere no distinct image is seen, because the rays of light come to the eye converging, a condition incompatible with distinct vision. At the center the eye sees only its own image, (and must be held very steady for that,) as the mir-

ror returns to the eye, when the eye is in that position, only those rays that fall from it, and none other.

Beyond the center the face is seen before the mirror, a small and inverted *image*, inverted because the rays of light cross each other at the focus. The influence of habit is very strong in some persons, and although the image, when inverted, is in reality before the mirror, yet most persons consider it behind the mirror, corresponding to their former impressions, and with some it is difficult for prejudice to give way to fact. Other persons who have their imaginations under the control of will, can make the image appear before or behind the mirror almost at pleasure. But if evening be taken as the time of experiment, and a lamp or lighted taper taken for the radiant object, the position of the image will not be subject to the caprices of prejudice or will,—the light will be too strong and the image too distinct.

In a less enlightened age, when it was not generally known that concave mirrors would form images in the air, showmen would frequently astonish their patrons by exhibiting strange and surprising appearances. By concealing both the object and the mirror behind screens, and giving only a side view to the focus, the cunning conjuror could call forth a skull, a pistol, a dagger, &c. If a fine transparent cloud of smoke is raised around the focus, the image of any illuminated object will be depicted in the middle of it with great beauty and effect. A purse of money, a golden trinket, or a sacred cross, may allure a spectator to put out his hand to attain it, but at that instant a grinning imp and an unsheathed dagger, make him as quickly withdraw.

(Art. 95.) As concave mirrors can arrest rays of light and reflect them in an opposite direction, they are very advantageously used in light-houses, to throw all the light *seaward*. For this purpose the mirrors are commonly made of copper, plated with silver and highly polished.

Concave mirrors have also been used to concentrate the rays of the sun into a focus for the purpose of *burning*.

The most celebrated ever known was made by a Frenchman, at Lyons; it was nearly four feet in diameter, and focal length thirty-eight inches. It melted silver and copper very readily, and even fused some of the almost infusible

earths; yet this heat is of very little practical utility for the want of volume.

Burning mirrors may be constructed by the combination of a great number of plane mirrors, all reflecting the sun's rays to the same point.

It is supposed that it was in this way that Archimedes set fire to the Roman fleet in the harbor of Syracuse.

Buffon, the celebrated naturalist, constructed a burning apparatus on this principle, and with one hundred and fifty-four mirrors, he was able to fire combustibles at the distance of two hundred and fifty feet.

CONVEX MIRRORS.

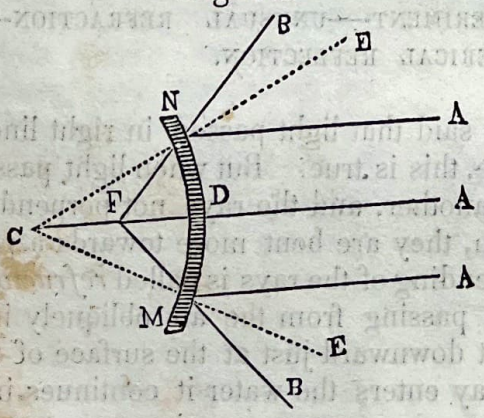
(Art. 96.) Convex mirrors may be explained on the same principle as concave mirrors, by considering the mirror, however large, as made up of a succession of plane mirrors; the point where any ray of light strikes reflects the ray so that the angle of reflection shall be equal to the angle of incident.

The action of a convex mirror is in many respects the converse of that of a concave mirror.

A concave mirror collects the reflected rays of light to a focus; the *same* mirror reflecting from its *convex* surface, disperses the rays of light from the *same* focus.

Concave mirrors collect rays, convex mirrors scatter them. Images behind a concave mirror are larger than their objects. Behind a convex mirror they are smaller.

Fig. 88.



For a more definite illustration let *MN* represent a very small section of a convex mirror. *C* the center of the sphere, *CA* the axis, *AM* and *AN* parallel rays. These rays will be reflected in the direction *MB* and *NB*, and form a *virtual focus* in *F*. The lines *CME* and *CNE* are perpendicular to the mirror, and by the law of reflection, the angles *AME* and *EMB* are equal, and it is easy to prove that *MF* and *FC* are

equal; and in case of a very small section of the mirror, *MF* may be considered equal to *FD* But *FM* is equal to *FC*, therefore *FC* and *FD* are very nearly equal. That is, the focus or *virtual focus* for parallel rays is half way between the center of the sphere and the mirror, the same as in the concave mirror.

When the rays of light do not fall parallel with the axis, but diverge from a point, the *virtual focus* is brought nearer the mirror, and the reflected rays are more dispersed.

When the rays of light converge on to the surface of a convex mirror, the reflected rays may be made parallel, or even converging to a point before the mirror. Thus, in the last figure *BM* and *BN* may be taken for the radiant rays, then *NA* and *MA* will be the *reflected rays*, and if the radiant rays converge still more, the reflected rays may meet at a point before the mirror.

Now as rays of light can converge from many objects at once, and be reflected to one point, this fact will account for convex mirrors showing whole streets, squares, and landscape scenery in almost exact miniature behind its surface.

CHAPTER III.—REFRACTION—CONSTANT OF REFRACTION—ATMOSPHERIC REFRACTION—MULTIPLYING GLASSES—DR. WOLLASTON'S EXPERIMENT—UNUSUAL REFRACTION—LOOMING—ATMOSPHERICAL REFLECTION.

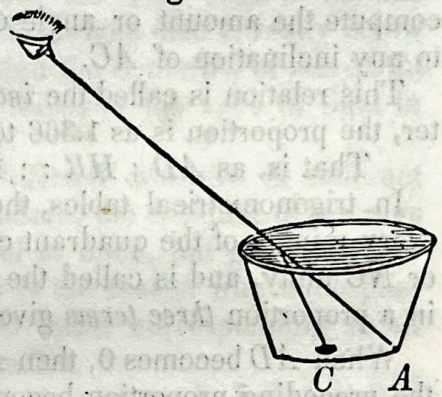
(Art. 97.) We have said that light passed in right lines, and in a general sense, this is true. But when light passes from one medium to another, and the rays not perpendicular to the new medium, they are bent more towards a perpendicular, and this bending of the rays is called *refraction*. Thus, a ray of light passing from the air obliquely into water, the ray is bent downward just at the surface of the water, but after the ray enters the water it continues in a right line.

It is this bending or breaking of the rays of light that causes oars, or any long rods or poles, when one end is in

the water and the other out, to appear as broken at the surface of the water.

The refraction of light is made very sensible by the following simple experiment:—Place a piece of coin in an empty cup, and place the eye so that the coin shall be just invisible, hid by the side of the cup. Then let an assistant carefully turn water into the cup, keeping the eye in the same position. As the water is poured in, the coin will appear to rise with the water and become visible.

Fig. 89.

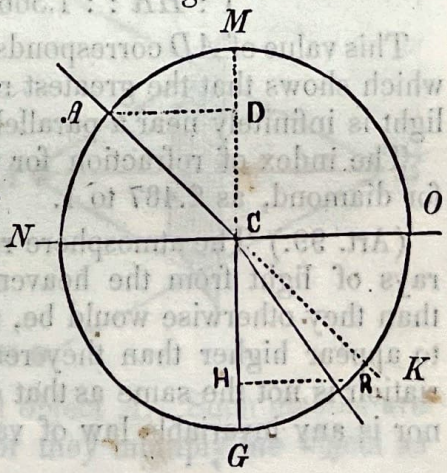


This experiment is represented by Fig. 89. The coin is at *C* at the bottom of the cup; but the eye can take no account of the bending of the rays of light, and therefore it must appear at *A* in the direct line from the eye. Indeed, the bottom of the whole cup appears to rise by refraction, and thus rivers and ponds appear to be less deep than they really are, and no doubt, most serious disasters have arisen from this cause, for water six feet deep rarely appears more than four.

(Art. 98.) All transparent bodies that permit the rays of light to pass through them, possess the power of refraction, but different bodies have different refractive powers.

Thus, air refracts; water, more than air, and glass more than water; but philosophers have discovered by experiments that each *medium* has a constant law of refraction for all angles which the incident ray may make with the surface of the refracting *medium*.

Fig. 90.



To explain what is meant by this law, suppose *NO*, (Fig. 90,) to represent any refracting surface, and *AC* a ray of light. From *C* as

a center, describe a circle. Draw *MCG* perpendicular to *NO*. From *A* draw *AD* perpendicular to *MC*, and this line, in the language of trigonometry, is called the *sine* of the angle *AMC*, *or the sine of the angle of incident.* If the ray *AC* were not refracted it would pass to *K*, but in consequence of refraction, the ray *AC*, after it enters the new media, takes the direction *CR*, and *RH is the sine of the refracted ray.*

Now for the same media, RH has a constant relation to AD; and when once that relation is determined, we can compute the amount or angle of refraction corresponding to any inclination of *AC*.

This relation is called the *index of refraction.* For water, the proportion is as 1.366 to 1.

That is, as $AD : HR :: 1.366 : 1$

In trigonometrical tables, the value of *AD* is given for every minute of the quadrant corresponding to radius *MC* or *NC* unity, and is called the *natural sine*; then we have in a proportion *three terms* given to find the fourth.

When *AD* becomes 0, then *AC* coincides with *MC*, and the preceding proportion becomes

$$0 : HR :: 1.366 : 1$$

$$\text{Hence } HR = \frac{1 \times 0}{1.366} = \frac{0}{1.366} = 0.$$

This shows that a perpendicular ray suffers no refraction.

When *AC* coincides with *NC*, then $AD = 1$, and our primitive proportion becomes

$$1 : HR :: 1.366 : 1.$$

This value of *AD* corresponds to the greatest value of *HR*, which shows that the greatest refraction is when the ray of light is infinitely near a parallel with the refracting surface.

The index of refraction for flint glass is as 1.584 to 1; for diamond, as 2.487 to 1.

(Art. 99.) The atmosphere refracts light or bends all the rays of light from the heavenly bodies more downward than they otherwise would be, and this causes those bodies to appear higher than they really are, but the law of variation is not the same as that described in the last article, nor is any invariable law of variation established.

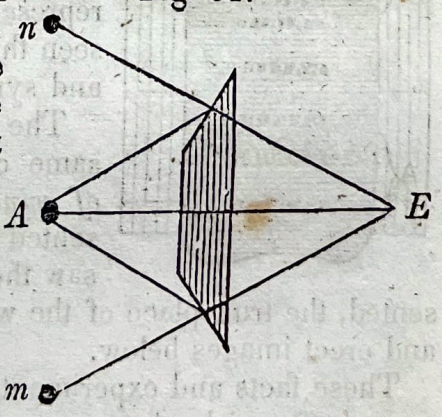
From the zenith, where the refraction is *zero*, down to the altitude of 45°, where it is 57 seconds, the variation or increase of refraction is very nearly as the tangents of the zenith distances, but from the altitude of 45° to the *horizon*, this variation ceases, and becomes very complex. In truth, observation alone seems to have settled the mean atmospheric refraction at small altitudes, and at the horizon at the mean temperature, is about 33 minutes of a degree, or a space a little wider than the sun's apparent diameter. From this it follows that when we see the lower edge of the sun or moon just on the horizon, the whole disc is really below it and would be invisible behind the convexity of the earth, were it not for the bending round of the rays of light in their passage through the air.

As the atmosphere is of different densities at different distances from the earth's surface, the bending of the rays of light do not take place all at once, but gradually, or in a curve, and probably this is the reason why atmospheric refraction has no constant index corresponding to all angles like other refracting media.

(Art. 100.) That the reader may be made fully sensible of the influences of refraction, and that it may be brought to account for some very unusual appearances, we here describe the following striking experiment:

Obtain, if possible, a piece of glass with two of its opposite surfaces plane and parallel, and two of its opposite ends plane and converging, as represented by Fig. 91.

Fig. 91.



Let A represent any small object, and the eye placed at E. The object A can be seen directly through the glass, but some rays of light pass from the object to the oblique end surfaces, as represented in the figure, and these rays are refracted by the glass, and also meet the eye at E, and the observer will perceive the two images m and n, as well as the direct object A. Such glasses are called *multiplying glasses*, for they multiply the object as

many times as there are plane surfaces so inclined as to refract rays to any single point.

This experiment shows that strange and singular appearances may be accounted for by refraction, *and that we conceive objects to be in direct lines with the last ends of the rays that meet the eye.*

A very clear and transparent piece of *ice*, cut in the proper shape, may serve as a multiplying glass.

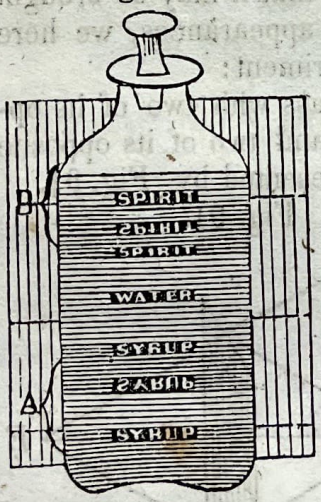
(Art. 101.) It should be distinctly borne in mind that different substances have different refractive powers, and the same substance will refract differently at different temperatures.

The refractive power of the atmosphere varies very much by the variations of heat and cold, as any one may convince himself by looking at objects over the surface of a hot iron, or over the surface of a wall or painted board when heated by the sun.

To show the different refractive powers of different liquids, Dr. Wollaston made the following experiment:

He took a square vessel of clear glass (Figure 92,) and poured into it a small quantity of clear *syrup*, and above this he carefully poured in an equal quantity of *water*, which gradually combined with the syrup, as seen at *A*. The word *syrup* upon a card held behind the vessel appeared erect when seen through the syrup, but inverted, as represented in the figure, when seen through the mixture of water and syrup.

Fig. 92.



The Doctor then put nearly the same quantity of *rectified spirits of wine* above the *water*, as represented in the figure at *B*, and he saw the appearance as there represented, the true place of the word spirit, and the inverted and erect images below.

These facts and experiments will in part, if not entirely, account for such phenomena as are usually denominated *unusual refraction*, looming, mirage, &c. appearances which

more nearly correspond with our ideas of magic, than with the more ordinary effects of natural causes.

We extract the following facts from Brewster's optics:

"The elevation of coasts, mountains, and ships, when seen over the surface of the sea, has long been observed and known by the name of *looming*. Mr. Huddart described several cases of this kind, but particularly the very interesting one of an *inverted image* of a ship seen beneath the real ship. Dr. Vince observed at Ramsgate a ship, whose topmasts only were seen above the horizon; but he at the same time observed in the field of his telescope two images of the complete ship in the air, both directly above the real ship, the uppermost of the two being erect and the other inverted."

The cases of elevated and depressed images may be explained by supposing the existence of volumes of heated or condensed air, and perhaps mixed with watery vapor, driven into a body like a volume of smoke, and the shape of this body of air resembling that of a *multiplying glass*, (Art. 100,) and elevated images correspond to *n* in that figure and depressed images to *m*.

"On the 28th of June, 1820, Captain Scoresby, in the Greenland seas, saw from the mast head of his ship, eighteen other ships at the distance of about twelve miles. One of them was drawn out in a vertical direction, another was contracted in the same direction; one had an inverted image immediately above it; and two others had two distinct inverted images above them, accompanied with two images of the strata of ice."

"In 1822, Captain Scoresby recognized his father's ship, the Fame, by its inverted image in the air, although the ship itself was below the horizon. He afterwards found that the ship was seventeen miles beyond the horizon, and its distance thirty miles. In all these cases the image was directly above the object; but on the 17th of September, 1818, MM. Jurine and Soret observed a case of unusual refraction, where the image was on one side of the object."

"One of the most remarkable cases of mirage was observed by Dr. Vince. A spectator at Ramsgate sees the tops of the four turrets at Dover Castle over a hill between Ramsgate and Dover. Dr. Vince, however, on the 6th of

August, 1806, at 7 P. M. saw the whole of Dover Castle, as if it had been brought over and placed on the Ramsgate side of the hill. The image of it was so strong that the hill itself was not seen through the image."

Some of these unusual appearances must be ascribed to reflection as well as to refraction. There is nothing improbable in supposing that the vapors and clouds may sometimes form mirrors, plane, convex and concave, and behind them or before them images of objects may be seen direct or inverted, according to the general surface of the mirror. Indeed we have had many vague accounts of travellers over mountains seeing their own images reflected from the air and from the clouds; very faint and distorted images, it is true, but sufficiently distinct and definite as to leave no doubt of the fact.

"A bark about 4000 tortoise distant was seen approaching Geneva, (Switzerland,) by the left bank of the lake, and at the same moment there was seen above the water an image of the sails, which, in place of following the direction of the bark, receded from it, and seemed to approach Geneva by the right bank of the lake; the image sailing from east to west, while the bark was sailing from north to south. The image was of the same size as the object when it first receded from the bark, but it grew less and less as it receded, and was only one-half that of the bark when the phenomena ceased."

This phenomenon must, no doubt, be explained on the principle of reflection. A side mirror in the air must have existed.

The celebrated *fata morgana*, occasionally seen in the Straits of Messina, which has ever astonished the vulgar and perplexed philosophers, is not yet satisfactorily explained. Of course it must be by refraction or reflection from real existing objects, perhaps by a combination of both principles; or perhaps in that locality nature, as if in sport, makes a *kaleidescope* in the air.

The following is a description of one of these phenomena, taken from Dr. Brewster; but it is not sufficiently definite for a philosophical evidence of fact, as it does not inform us whether the images of *arches*, castles, villages, trees, &c., resemble each other at different times, or whether they were

ever recognized as the images of real objects known to be in the vicinity—although without direct assertion, we at once conclude this must be the fact; but here is the description:

"A spectator on an eminence in the city of Reggio, with with his back to the sun and his face to the sea, and when the rising sun shines from that point whence its incident ray forms an angle of about forty-five degrees, will see upon the water numberless series of pilasters, arches, castles well delineated, regular columns, lofty towers, superb palaces with balconies and windows, villages and trees, plains with herds and flocks, armies of men on foot and on horseback, all passing rapidly in succession on the surface of the sea. These same objects are, in particular states of the atmosphere, seen in the air, though less vividly; and when the air is hazy, they are seen on the surface of the sea, vividly colored, or fringed with all the prismatic colors."

We have before remarked, that some of these singular appearances must be ascribed to reflection, but clear and definite evidence is wanting; however, we have found the following fact in the Edinburgh Encyclopedia:

"Walking on the cliff," says Dr. Buchan, "about a mile to the east of Brighton, (England,) on the morning of the 18th of November, 1804, while watching the rising of the sun, I turned my eyes directly towards the sea just as the solar disc emerged from the surface of the water, and saw the cliff on which I was standing represented precisely opposite to me at some distance on the ocean. Calling the attention of my companion to this appearance, we soon also discovered our own figures standing on the summit of the opposite apparent cliff, as well as the representation of a windmill near at hand. The reflected images were most distinct, precisely opposite to where we stood, and the false cliff seemed to fade away, and to draw near to the real one, in proportion as it receded towards the west. This phenomenon lasted about ten minutes, till the sun had risen nearly his own diameter above the sea. The whole then seemed to be elevated into the air, and successively disappeared, like the drawing up of a drop scene in a theatre. The surface of the sun was covered with a dense fog of many yards in height, and which gradually receded before

the rays of the sun. The sun's light fell upon the cliff at an incidence of about 73° from the perpendicular."

The following is a remarkable instance of reflection, and the same thing may be observed on a small scale by looking at small objects not very distant, over the surface of hot iron. By a little care in adjusting the eye we may see the real objects and their inverted images immediately below.

"While the French army was marching through the sandy deserts of Lower Egypt, they saw various phenomena of unusual refraction, to which they gave the name of *mirage*. When the surface of the sand was heated by the sun, the land seemed to be terminated at a certain distance by a general inundation. The villages situated upon eminences appeared to be so many islands in the middle of a great lake, and under each village there was an inverted image of it. As the army approached the boundary of the apparent inundation, the imaginary lake withdrew, and the same illusion appeared round the next village. M. Monge, who has described these appearances in the *Memoires sur l'Egypte*, ascribes them to reflection from a reflecting surface, which he supposes to take place between two strata of air of different densities."

Chap. IV.—Chromatics, or the decomposition of light—the prism—colors in light—three primary colors—the solar spectrum—the heating point of the spectrum—the rainbows, primary and secondary—the color of bodies.

(Art. 102.) It is all-important that we should not deceive ourselves, and therefore let us acknowledge, in all candor and humility, that we know nothing of the essential nature of light. We know not whether it is an action or a substance, a principle or an effect—but from all that we can learn, we incline to the belief that light is a *substance* of an extremely ethereal nature everywhere existing in and above the air, and in every transparent body. *Light*, *electricity*, and *heat*, may or may not be one and the same principle,

or all three may be only different effects or different modifications of the same principle. We mentioned in a former chapter that there are two theories concerning light—one that it is a substance emanating from luminous bodies, the other that it is a substance already present in the air and in every transparent body, and made to vibrate and undulate, like waves on water, by some mysterious agency of luminous bodies. Modern philosophers are inclined to the latter theory; but to explain every consideration that leads them that way would require more space than could possibly be given in a work like this.

The principle evidence that light is a material substance is derived from the fact, that it can be decomposed by refraction into seven different colors.

To show the decomposition of solar light, obtain a glass prism, and let a small body of rays pass into a dark room, through a small aperture in a close window shutter, and immediately after they pass in, let them meet the prism, through which they will pass and be refracted by it, but the refracted rays will spread, and form *seven prismatic* colors. They are called *prismatic* colors, because they are the colors made by the refraction of the *prism*—and they are *red*, *orange*, *yellow*, *green*, *blue*, *indigo*, and *violet*.

Fig. 93.

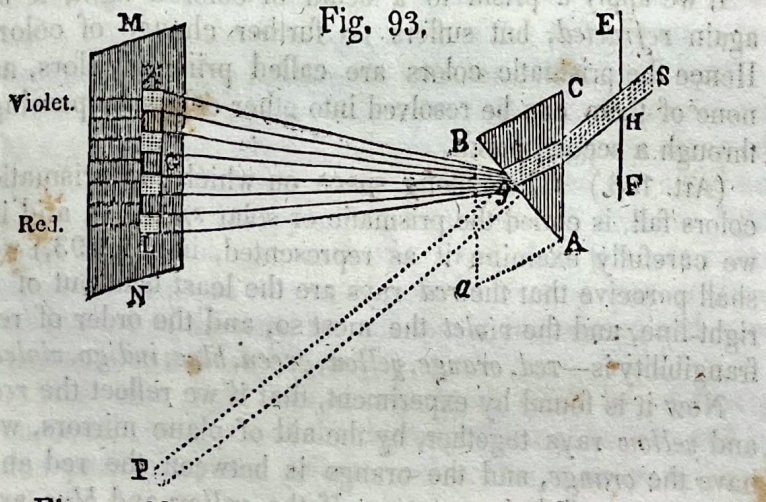


Figure 93 represents this experiment. *S* is a sunbeam. *H* is the aperture in the shutter. *A B C* is the prism. Now if *H* is small and the distance to the opposite wall *g G* considerable, then the colors will be very

bright; the red will be least refracted, and the violet will be refracted the most, as represented in the figure.

There are no distinct lines of demarcation between the colors; that is, no one can exactly define where the red ends and the orange begins; and so with the other colors. Indeed the spaces between the distinct colors are of hues indefinable.

If we apply another *prism*, as *ABa* immediately behind the first, to refract the rays back again, they will unite and produce white light. Hence it follows that *white light contains all the seven colors.*

If we take seven powders, corresponding in proportional quantity and colors to the prismatic colors, and mix them together, the compound will be nearly white—so near, that we may reasonably conclude that it would be perfect white, provided we could really mix them in the exact and true proportions required by nature. The same result will be obtained if we divide a circle into seven sections, in proportional size as the colored spaces, and color each section—one red, another orange, &c.—and then make this circle rapidly revolve on its center, no one color can then be distinctly seen, but the compound blending of all will be a grayish white.

If we apply a prism to a beam of colored light, it is again *refracted*, but suffers no further change of color. Hence the prismatic colors are called primary colors, as none of them can be resolved into other colors by passing through a second prism.

(Art. 103.) The oblong space on which the prismatic colors fall, is called the prismatic or solar *spectrum*, and if we carefully examine it as represented, in (Fig. 93,) we shall perceive that the *red* rays are the least bent out of a right line, and the *violet* the most so, and the order of refrangibility is—*red, orange, yellow, green, blue, indigo, violet.*

Now it is found by experiment, that if we reflect the *red* and *yellow* rays together, by the aid of plane mirrors, we have the *orange*, and the orange is between the red and yellow rays of the spectrum. If the *yellow* and *blue* are thrown together by reflection, we have the intermediate color *green;* the *red* and the *blue* gives a *purple.*

These facts seem to indicate that *orange* is not an ori-

ginal or primary color, but an admixture of the red and yellow; and that green is only an admixture of the yellow and blue; and indeed, many modern philosophers are of opinion *that there are only three primary colors, red, yellow, and blue*, and this opinion would be at once adopted by all, provided we could decompose the orange into red and yellow, or the green into yellow and blue.

But the simple fact that we cannot decompose any color is no proof that it is not a compound—it is only a proof of our inability to analyze.

(Art. 104.) The different colors of the spectrum have different degrees of illuminating power, as may be shown by the following experiment:—Place some very fine print in the spectrum, and it can be read at a much greater distance when it is in the yellow rays, than when in any others, and from the yellow the illuminating power decreases both rays, and is very inconsiderable in both the violet and the red. The sun's light is accompanied by heat, and the different colored spaces in the spectrum have very different effects on the thermometer.

The heat is least in the violet, and gradually, but not uniformly, increases downward to the red, but it is greatest of all in the dark space below the red. From this we conclude that color and heat are separate constituents of solar light, and that the heating quality of the solar beam is refrangible, but less refrangible than the red rays of light.

(Art. 105.) When the solar spectrum is closely examined by a microscope, many hundreds of dark lines are observed irregularly scattered through it. Some have attempted an explanation of this by saying that *waves* of different light meet and counteract each other, and thus produce darkness, the same as two equal sounds meeting may produce an instant of silence; but all this is too minute and conjectural for a work like this.

The solar light has a very great effect in producing chemical changes and the decomposition of bodies, and in this particular, the different colored rays have different effects.

The yellow rays apparently control the growth of plants, and make their leaves turn green; the blue rays more readily decompose the iodides and chlorides of silver,

bodies which are used in the Daguerreotype art, or the art of fixing the images of bodies on prepared silver plates by means of this chemical action of light.

Mrs. Somerville, of England, has made many and varied experiments on the solar spectrum, and one of her most remarkable results is, that of magnetizing steel needles in the violet rays—but whether it was the color of light or the heating, or the chemical quality of this part of the spectrum, or a peculiar ray of itself that magnetized the steel, it is impossible as yet to decide, but as a summary to the foregoing we may repeat,

1st. That the solar rays are composed of at least three primary colors, *red*, *yellow*, and *blue*.

2d. That the illuminating rays and the heating rays are independent and separate of each other, and independent of the colored rays.

3d. That there are chemical rays, and magnetic or electrical rays, but whether the same or distinct from the illuminating or heating rays is not at present determined.

(Art. 106.) Prisms made of different kinds of glass, such as crown glass and flint glass, give different degrees of refrangibility to the same colors, and every different substance of which prisms can be made, seems to have a spectrum of its own.

A prism may be made with three pieces of plate glass put together in a triangular shape and sealed water tight at the edges, closed at one end and prepared with a cork or stopper at the other. When this is filled with water and held in a sun beam, it refracts a solar spectrum, and by filling it with different liquids, it is found that one liquid will make a larger spectrum than another, and when filled with the oil of cassia, the spectrum formed by it will be more than twice as long as that formed by a prism of solid glass. The oil of cassia is therefore said to have a greater dispersive power than glass, for in fact it disperses the rays of light to a greater distance.

Drops of water refract and decompose light, giving the prismatic colors, thus fully accounting for the phenomena of the rainbow.

The RAINBOW, as every one knows, is a luminous arch in opposite direction from the sun, and is never seen unless

rain drops are falling in the direction in which the bow is seen, and the rays of the sun or moon (rarely the latter) pass through them in a manner which we will shortly explain. When the rain drops are large and well formed, and the sun shines quite bright, and its altitude low, two bows are seen; the smaller and inner one, which is the brighter of the two, is called the primary bow; the larger and fainter one is called the secondary bow. As the secondary bow is sometimes not seen in connection with the primary, and whenever it is seen, the primary bow is very distinct and bright, a general opinion has been created among those who are not philosophers, that one bow is a reflection of the other. A remarkable instance of the easy introduction of error, and the difficulty of eradicating it, for according to the best of our information and judgment, few persons who think at all on the subject, will give up the popular error,* unless they enjoy a full and philosophical knowledge of the subject.

The ends of the bow, the parts nearest the ground, are commonly brighter than the uppermost part of the arch; sometimes the upper part of the arch is quite invisible, or in fact is not in existence, because the drops in the higher regions of the air are not sufficiently formed to reflect and refract the rays of light, but become larger and more perfect as they unite in their approach to the ground, and then cause the appearance of the bow.

If any one doubts that it is drops of rain that cause the appearance of the rainbow, let him place himself between the sun and the spray of a water fall, as at Niagara,—or he may go into water when the sun is low, place his back to that luminary, and strike on the water to raise a spray, and a distinct rainbow will be seen.

The center of the bows is in a line directly opposite to the sun; and of course when the sun is high, the bow must be low; when the sun is more than 42° of altitude, the primary bow is never seen, it then being in a direction below the horizon. When the sun's altitude is more than 54°, the exterior bow is never seen for the same reason, and

* The equinoctial storm is another popular error quite prevalent and universal, because violent storms frequently do occur about the equinoctial periods.

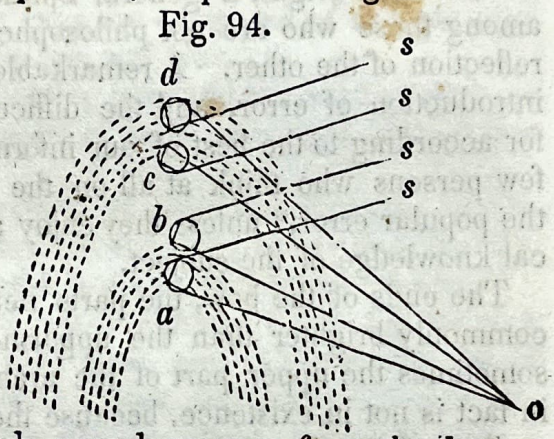
this accounts for rainbows never being seen except morning or evening.

When the sun is in the horizon, the bow is semi-circular: bows larger than semi-circles may be seen from points above a cataract, or from the mountain cliffs when the sun is low.

The semi-diameter of the interior bow, found by observation, is 42°, its angular breadth 2° 10′, the arch between the two bows 8° 30′; the breadth of the outer bow 3° 10′.

To give a philosophical explanation of the rainbows in as brief a manner as possible, we present Fig. 94.

Fig. 94.



Let *s*, *s*, *s*, *s*, represent parallel rays of light from the sun. One of these rays, as here represented, strikes the upper part of the drop *a*, is there refracted into rays of several colors. One of these refracted rays strike the back part of the drop, and emerges from the drop on the under side, and meets the eye at *O*.

A similar ray of light strikes the upper part of the drop *b*, and in like manner is refracted and reflected and meets the eye at *O*. But the ray through *b* must not be so much refracted to pass to the same point *O*, as the ray through *a*, and *differently refracted rays show different colors;* the *violet* ray is most refracted, the *red* ray the least; therefore, the lower drops about *a* will show the *violet* color, and the upper drops about *b* will show the *red* color; and this corresponds with observation, as the upper part of the primary bow is *red*, and the lower part *violet*.

For an explanation of the extreme bow, it is only necessary to trace the rays of light *s*, *s*, which pass into the drops *c* and *d* on the under sides, and suffer *two reflections* within the drops, and after the last refraction, come to the eye at *O*.

To throw the last refracted rays to *O*, it is plain that the ray through the drop *d* must be *more refracted* than the ray

through the drop *c;* therefore in this bow the *violet* must be uppermost, the reverse order of the primary bow.

Now the situation of the various colors, the breadth of the bows, the fact that the exterior bow must be much fainter than the primary one, because the light suffers two reflections to form the exterior bow and only one to form the primary bow. In short, every particular in respect to the theory of the rainbows is confirmed by observation; therefore this theory or explanation must be true.

Lunar rainbows are seldom seen, and in the most favorable circumstances the colors are very faint, and scarcely perceptible.

Red rainbows, distorted rainbows, and small segments of rainbows on the grass have been seen. They are formed of water resting on the spiders' webs in the field.

(Art. 107.) The refractive power of the atmosphere gives different shades of light corresponding to the colors of the spectrum. Thus, soon after sun-set, the western sky appears *red*. When the sun descends lower, and brings us into more refracted rays, we have orange, then yellow, then twilight ends. No doubt the varied and gorgeous colors of the clouds, so often seen, depend upon the same principle.

ON THE COLORS OF NATURAL BODIES.

(Art. 104.) Before the discovery of the compound nature of light, it was supposed that one body was *red*, another green, another yellow, &c.—the same as one body was hard, another soft, another elastic, another brittle, &c.; that is, that color was inherent in the nature of the body.

Since that discovery, however, the color of bodies is supposed to be owing to the peculiar manner in which bodies reflect some of the rays of light and absorb others, or the chemical affinity which they may have to light, and to its differently colored rays.

But this subject is too difficult and complicated, and the nature and essence of light too little known, to have any definite theory as to the general doctrine of the color of bodies.

A body will exhibit its real color only in white and perfect light; for by looking at any body through a green glass, it will appear green, whatever be its color; the same

is true of a red or orange glass; and in truth any colored media will give bodies more or less its own color; thus, the distant mountains appear blue, from the blue air through which they are seen, and the sky (so called) is blue, or red, or orange, according to the state of the atmosphere.

Also, bodies amid the light of other bodies will partake more or less of their hue. Thus, a red wafer, put in the blue of the spectrum, will appear of a dusky tint, but of a brilliant red in the red space. Some bodies have this property more than others; the animal called the cameleon is said to change its color with great facility, and partake in a high degree of the color of any other body on which it may happen to be.

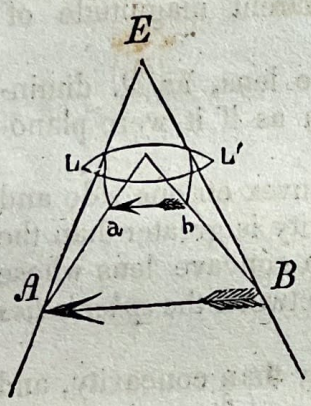
The different colors of vegetable life are unquestionably due to the action of light, for without light, or with less light, their colors will be more faint, if not quite changed; and when we consider the action of the solar light on the composition and decomposition, we are almost forced to reason as if light were material. But it is probable that we shall never understand the nature and principle of colors until we understand the nature and principle of light, and perhaps not then.

CHAP V.—LENSES—OPTICAL INSTRUMENTS—A SINGLE LENS—A MICROSCOPE—FOCAL DISTANCE OF A LENS—IMAGES OF OBJECTS FORMED BY THE REFRACTION OF LENSES—RULES FOR FINDING THE MAGNIFYING POWER OF A LENS—A SINGLE LENS TELESCOPE—AN ASTRONOMICAL TELESCOPE—THE DAGUERREOTYPE ART.

(Art. 108.) In the same medium, light travels in right lines; but in passing from one medium obliquely into another, light is bent out of its course, or refracted. Also, rays of light are thrown back from smooth surfaces. *Now all optical instruments, all microscopes and telescopes, are founded on the principles of refraction and reflection of light*; hence we have *refracting* and *reflecting* telescopes.

We always do, and always must ascribe the direction of an object to be in a right line with that portion of a ray of light from the object, which last meets the eye. In practice we can have no conception of light coming to us round a curve, or bent at an angle; the eye and the mind can only allow a right line from the eye to the object. But we can bend rays of light by refraction, as we have shown in several preceding chapters, and we are now to show how this simple principle may be made to magnify objects.

Fig. 95.



To show how an object may be magnified by means of refraction. Let *L L'*, Fig. 95, be a circular piece of glass, thickest in the middle and convex on both sides. (Such a glass is called a *lens*, and is in fact a simple *microscope*.) Let *a b* represent any small object placed near the lens. Rays of light pass from the extremities of the object *a* and *b* to the lens, and not striking perpendicular to the surface, they are *refracted* to the point *E*, where the eye is represented. From the center of the glass draw the right lines *aA* and *bB*, and between *A* and *B* we have the *image* of *ab*. For the eye at *E*, (so to speak) can perceive the point *a* as somewhere in the line *EA*, and the point *b* as somewhere in the line *EB*. But as the glass is circular in all directions, the refraction or projection is equal in all directions, and this can only be shown by drawing lines from the center of the glass; therefore *AB* is the true and magnified image of *ab*.

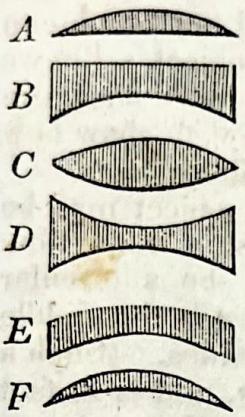
If *ab* were nearer to the lens, the image *AB* would also be nearer *L L'*, and of course not so much magnified. If *ab* were farther from the lens, the image would be farther off and more magnified; but it would be more *indistinct* for want of sufficient light to form so large an image.

When *ab* is so far from the lens as to make the lines from the center of the lens through the points *a* and *b* parallel to *EA* and *EB*, or inwardly *diverging* from them, then no image of the object *ab* can be formed.

All transparent media having curved surfaces, and used

for optical instruments, are called *lenses;* there are six different kinds as represented in Fig. 96.

Fig. 96.



The name of each lens is merely an expression of its shape.

We have just examined the action of the double convex lens *C*, the action of *A* is only one-half as much as if it were double convex.

The action of *B*, a concave lens, is the converse of a convex lens, that is, it diminishes the apparent magnitude of objects.

A double concave lens, as *D*, diminishes twice as much as if it were plano-concave.

A concavo convex lens as *E*, is convex on one side and concave on the other, but the concavity is greater than the convexity, and its action is that of a concave lens whose concavity is equal to the difference between the *sphericities* of the two sides.

A meniscus *F*, has more convexity than concavity, and of course its action is that of a *convex lens*, whose convexity is equal to the difference between the sphericities of its two sides.

From the description just given of the two lenses *E* and *F*, the pupil might naturally inquire why they are made, when in *effect* they are nothing but *concave* and *convex lenses*,—we reply, that a particular degree of concavity or convexity can be practically attained much easier by making lenses in the shape of *E* and *F* than by direct construction; but the more definite reasons of counteracting *lenses*, will appear as we advance.

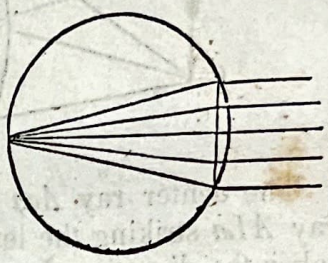
(Art. 109.) The surfaces of lenses, as we have just seen, may be of any regular curvature, but in practice, opticians have found it best to confine themselves to *spherical convex*, *spherical concave*, and *plane surfaces*.

A line drawn perpendicular through the center of any lens is called its *axis*, and of course the axis of a lens will pass through the center of the sphere of which the lens is a part. Rays of light passing to a lens parallel to its axis are called *parallel rays*. Rays converging towards the

axis are *converging rays.* Rays diverging from the axis are *diverging rays.*

Parallel rays, after being refracted by a lens, converge. The point where *most* of these converging rays meet is called the *focus.*

Fig. 97.



For a single convex lens, the focus for parallel rays is at the opposite extremity of the diameter of the sphere of which the lens is a part, as represented by Fig. 97.

For a double convex lens and parallel rays, the focus is at the center of the sphere.

For convergent rays the focus would be nearer the lens. For divergent rays, the focus would be at a greater distance, if the refracted rays formed a focus at all.

When the lens is a *meniscus*, and the rays parallel, we may find the focal distance by the following

RULE.—*Divide twice the product of the two radii by their difference, and the quotient will be the focal distance required.*

EXAMPLE. The radius of the convex surface of a meniscus is 10 inches, and of the concave surface is $11\frac{1}{4}$ inches: What is its focal distance?

By the rule $\frac{11\frac{1}{4}\times 10\times 2}{1\frac{1}{4}}=9\times 20=180$ inches, *Ans.*

By this example we readily perceive that a meniscus is the only practical shape to give a lens for a great focal distance, for it would be practically impossible to make an *accurate* plano convex lens of 180 inches focal distance.

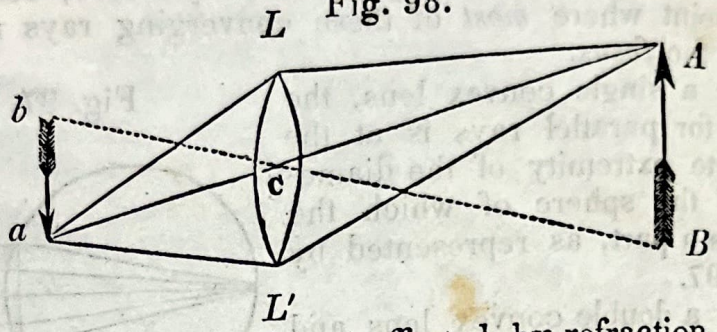
Parallel rays which meet concave lenses, diverge after refraction.

It has already been shown, (Art. 94,) that concave mirrors give inverted images of objects by *reflection.* We are now to show that convex lenses will give like images in the air by *refraction.*

Let *L L'* (Fig. 98,) represent a double convex lens; *AB* an object before it; conceive lines from the point *A* to strike on all parts of the lens, (and to avoid confusion we

shall only represent the two extreme rays, and the mid one passing through the center of the lens.)

Fig. 98.



The center ray *Aca* is not affected by refraction. The ray *ALa* striking the lens obliquely, is *refracted* at *L*, and takes the direction *La*.

The ray *AL'a* is more oblique than the last mentioned ray, and therefore is more *refracted*, taking the direction *L'a*.

Now these rays of light, and all others from the point *A*, which can fall on the lens between these extreme rays will meet after refraction at the point *a*, as their focus; and of course there form an image of *A*, if there is any media, even air, to arrest the rays of light.

In the same manner the point *B* will give an image at *b*, and every point in the object *AB* will have its corresponding focal point in *ab*, and thus form an inverted image, and in a certain sense at the *focus* of the lens.

Such images are made clearly visible by receiving them on a screen, or on smoke, or on the air only, if the eye is in a favorable position to receive the rays. When received on a volume of smoke or vapor, they appear as suspended in the air, and are called *aerial images*.

The magnitude and distance of such images must vary with circumstances. If the object *AB* (Fig. 98,) had been very remote from the lens, then the lines *AL* and *AL'* would have been much nearer parallel, and the image would have been much nearer the focus for parallel rays, and much smaller.

When the object is next to infinitely remote, as the sun or planets, then the rays are considered as parallel, and the image must be very minute in the principal focus of the lens. As the object approaches, the image recedes and becomes larger. When the object is at twice the focal

distance of the lens, the image is at the same distance on the opposite side, and is of the same magnitude as the object. As the object comes still nearer, the image recedes and becomes larger than the object, and when the object reaches the focus the image is at an infinite distance, if it can be said to exist at all.

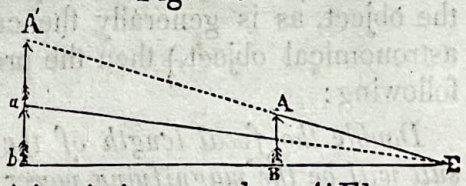
The human eye is most acute, in its power of vision, at the distance of about *six inches*, and the proper position to see one of these images is directly behind it, in a line with the lens.

If other rays of light are shut out, by a tube enclosing the lens and the image, and the eye placed about six inches behind the image, then the image will be seen very clear and distinct.

(Art. 110.) To explain the power of lenses in magnifying objects, or rather of giving magnified images to objects, we must consider the effects of distance in giving different apparent magnitudes to the same object. "If we look at any moderate sized object, say a man at the distance of half a mile, we only distinguish his general outline, but neither his age, nor dress can be recognized. When nearer, we discover the different parts of his dress, and still nearer, we perceive his peculiarity of features, and when quite near we may observe his very eye-lashes, and the most minute lines upon his face." This keenness of vision always corresponds to the angle of vision.

Let E represent an eye viewing a man ab, (Fig. 99.) at the distance Eb. The angle of vision is the angle aEb. When the man comes nearer and is AB, the angle of vision is increased to $A'Eb$.

Fig. 99.



Now ab is the apparent magnitude of the man at the distance Eb and $A'b$ is the apparent magnitude at the distance EB, and by proportional triangles we have the proportion

$$EB : Eb :: AB : A'b$$

If we take AB, the real magnitude of the object as unity, then the fourth term of the proportion will be

$$A'b = \frac{Eb}{EB}$$

This equation furnishes a rule to compute the increase of the apparent magnitude of an object corresponding to a decrease of distance.

RULE.—*Divide the greater distance by the less, and the quotient will be the increased apparent magnitude.*

(Art. 111.) Now let us suppose the man to be placed 70 feet before a lens of such a convexity as to form his image 25 feet on the other side of the lens; then his image will be inverted, and *one-third* of his real magnitude; but by placing the eye six inches from this image, its apparent magnitude is increased in the proportion of 6 inches to 100 feet, or, by the preceding rule, 200 times. That is, an image one-third of the size of the man is magnified 200 times, or the apparent magnitude of the man is increased one-third of 200, or 67 times nearly.

To find the magnifying power of a convex lens, when the eye views the image at the distance of six inches, we have the following

RULE.—*Multiply the distance between the object and the image by the distance of the image from the lens, and double the product. Divide this sum by the distance of the object from the lens.*

If we apply this rule to the case just cited, we have $\frac{100\times25\times2}{75}=\frac{200}{3}=67$ nearly, the same as before.

When the image is incomparably nearer the lens than the object, as is generally the case, (always so, with any astronomical object,) then the preceding rule becomes the following:

*Double the focal length of the lens in feet, and the result will be the magnifying power.**

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* NOTE. Those pupils who have acquired a little insight into algebra and geometry, can readily understand the method of obtaining these rules—and this mathematical part is the true essence of philosophy.

In Fig. 98. the two triangles ACB and acb are similar. Let the whole perpendicular distance between the object and image be represented by D, the distance between the image and the lens by f; then the distance between the

If we take the *meniscus* spoken of in (Art. 109,) whose focal distance is 180 inches, or 15 feet, and put it in one end of a tube 15 feet and 6 inches long, and put the eye at the other end, we then have the simplest *telescope* possible, with a magnifying power of 30, a power sufficient to see the satellites of Jupiter with ease and distinctness.

If in place of looking at the image with the unassisted eye at the distance of 6 inches, we view it through a small convex lens, or eye-glass, such as is described in (Art. 108),

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object and the lens will be $(D-f)$. Also, let the size of the object $AB=1$, and represent the size of the image, by I.

Then by proportional triangles, we have

$$D-f : 1 :: f : I.$$

$$\text{Therefore } I=\frac{f}{D-f}.$$

This is a general expression for the size of the image, The numerator is the distance of the image from the lens, and the denominator is the distance of the object from the lens. When these are equal, the image is unity, the same as the object. When D is very great, I or the image must be very small.

Now by the rule given in Art. 110, when the eye is placed 6 inches or $\frac{1}{2}$ foot from this image its apparent magnitude is increased in the proportion of $\frac{1}{2}$ foot to D feet, or the image is as many times greater as there are units in $(2D)$ feet.

Then the apparent magnitude of the image will be expressed by $\frac{2fD}{D-f}$ which symbol put in words gives the rule in Art. 113.

If we divide the numerator and denominator of this fraction by D, we shall not change its value, but its form will then be $\frac{2f}{1-\frac{f}{D}}$. Now when D is very great in relation to f, the fractional part of the denominator is very near zero. Practically it is zero, and the value of the expression is simply $2f$, which is the modified rule.

the image will then be seen and magnified as a *real* object; and suppose the eye-glass or microscope magnifies 10 times, then the magnifying power of our telescope is 30×10 or 300, and here we have the *Astronomical refracting telescope.**

(Art. 112.) It is a well known fact that light has a chemical effect on many substances; it deepens the colors of living plants, and fades dead vegetables; it also acts with great power on some of the gasses, particularly chlorine and iodine; and these gasses have a great affinity or corroding effect when brought in contact with silver, forming chlorides and iodides of silver.

Now as by means of a convex lens we can concentrate an image of any object near the focus of the lens, we can so place a plate of the chloride or iodide of silver that the light which forms the image of any person or thing shall rest on the plate, and this light, by its instant chemical action, makes a permanent picture of the image on the plate, and this is called the Daguerreotype art, from Daguerre, a Frenchman, who first brought it into notice only a few years ago.

Chapter VI.—Spherical aberration—chromatic aberration—efforts to destroy aberration—difficulties to be overcome in constructing a telescope—dispersion of light—irrationality of dispersion—Mr. Hasart's telescope—achromatic lens—achromatic eye-piece—microscopes and telescopes compared—reflecting telescope.

(Art. 113.) In the preceding chapter care was taken to give only general and fundamental principles that they might be well fixed in the mind of the learner before the confusing effects of difficulties and inaccuracies are presented.

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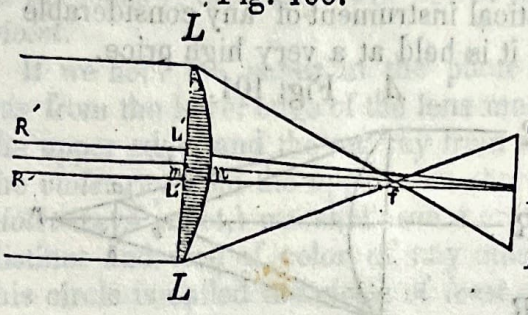
*The principles of forming images by concave mirrors, as explained in a former chapter, in combination with the principle of the action of lenses in this chapter, give the fundamental principles of ALL optical instruments. We therefore recommend this portion of the work to the most serious attention.

We have hitherto supposed that a lens refracted all the rays of light to one focus, but this is not strictly true.

Fig. 100.



Let LL (Fig. 100) represent a plano convex lens, and conceive parallel rays to fall on its surface, as represented in the figure. The extreme rays will be brought to a focus in f, and the rays near the axis to a focus in F. The intermediate rays will meet in all points between f and F. Continue the lines Lf and Lf to G and H on a plane passing through F. This multitude of foci arising from the refraction of any *spherical* surface is called *spherical aberration;* the distance fF is called *longitudinal spherical aberration*, and the distance GH the *latitudinal spherical aberration.* In the plano convex lens, as here represented, the distance fF is $4\frac{1}{2}$ times the thickness of the lens; but when the lens is turned the other way and its convex side presented to the parallel rays, then the aberration is only $1\frac{17}{100}$ths of the thickness of the lens. A double convex lens with equal convexities gives the aberration at $1\frac{67}{100}$ths the thickness of the lens.

The lens which has the *least aberration* is a double convex one, whose radii are as 1 to 6, and the side of greatest convexity turned towards the parallel rays—with such a lens the aberration is only $1\frac{7}{100}$ths of its thickness.

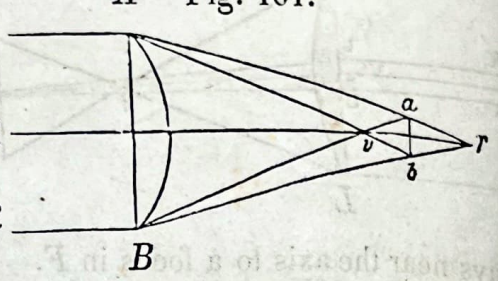
The aberration may be much reduced by covering up the exterior portions of the lens; but the advantage thus gained, (as a general thing,) would be too dearly purchased by the loss of light; but the difficulty of overcoming aberration will be considered in a subsequent article.

Unless spherical aberration is in some way destroyed, it is obvious that a lens cannot form a distinct image of an object, and in the history of telescopes, this has been a serious difficulty, and as yet but partially overcome. But spherical aberration is not the only difficulty in the way of forming distinct images of objects, by lenses—there are

several others, as we shall show in the next article, and they must all be overcome together before a perfect telescope can be constructed, and for these reasons it is rare to find even a good optical instrument of any considerable size, and when found, it is held at a very high price.

(Art. 114.) In the preceding chapter no notice was taken of the fact, that light separates into seven different colors by refraction, as learned by the action of the prism, (Art. 102.)

Fig. 101.



In proportion to its power of refraction, a lens decomposes white light; that is, a lens made of a particular substance or kind of glass. But we may have another lens made of another kind of glass which will refract as much as the first, but will have a greater or a less decomposing power. In other words, the last mentioned lens may separate the colors more or less than the first, and then, in the technical language of optics, it is said to have a greater or less *dispersive power*.

Let *AB* (Fig. 101,) represent a lens. The ray of light along the axis is not refracted. The more remote rays are refracted, but by *refraction*, they are separated into colors; the *violet* rays are most refracted and meet in a focus *v* nearest the lens; the *red* rays are least refracted and meet in a focus farthest from the lens, as represented in the figure. The other prismatic colors have their foci between *v* and *r*, and the distance *vr* is called the *chromatic aberration* of the lens, or in plain English, the aberration of color.

It is plain that in any lens, the *spherical* and the *chromatic* aberrations are confounded together, and together they must give a very confused image of any object.

We can show chromatic aberration apart from spherical aberration by covering up the center of the lens, and leaving only a circular border for the solar light to pass through.

Now if we hold a piece of white paper at the focus *v*,

we shall see circles of colored light, the center will be *violet* and the outer border *red*. If we hold the piece of paper at the focus *r*, the center will be *red* and the outer border *violet*.

If we hold the paper in the plane *ab* (where the violet ray from the lower edge of the lens meets the *red* ray from the upper edge, and the *red* ray from the lower edge meets the *violet* ray from the upper,—in short, where the *red* and *violet* rays meet,) we shall see a circle of light the most distinct and free of color of any other to be found, and this circle is called the circle of *least aberration*.

(Art. 115.) After a careful examination of Art. 113 and 114, it will be apparent to the reader that there are serious difficulties in the way of making a *perfect* refracting telescope, and with these difficulties we may mention the following:

1. Spherical aberration.
2. Chromatic aberration.
3. Want of sufficient light.
4. Want of an ample field of view.
5. Imperfection of glasses, or the almost impossibility of obtaining it in pieces sufficiently large, entirely free of all specks and veins.
6. Imperfections in mechanical construction.

After a great amount of study and perseverence by different individuals, these difficulties are nearly, if not entirely overcome, and we shall show the possibility of surmounting them, commencing with

SPHERICAL ABERRATION.

(Art. 116.) By inspecting Fig. 100 we shall perceive that to form a common focus for all the rays of light, it is necessary that the curvature should be greater about the center of the lens, and such a shape corresponds to sections of ellipses and hyperboles, and lenses of such curvature do in fact correct spherical aberration, but at the same time they were found to increase chromatic aberration, a still greater inconvenience; and it is said that Newton, on observing this, gave up the improvement of the refracting telescope as hopeless, and bestowed his attention to reflectors.

But we cannot stop to detail the experiments and investigations of philosophers; we must jump to conclusions.

Spherical aberration can be *wholly removed* by a much less objectional method, by combining a convex lens with a meniscus, but owing to the short focal length of the combination, such a compound glass would not answer for the object glass of a telescope, nor is it free from chromatic aberration.

After much trial and investigation it was found that spherical aberration could be removed by the same artifice that removed chromatic aberration, therefore we may at once turn our attention to

CHROMATIC ABERRATION.

(Art. 117.) A lens would be of no use, if it were not for its power of refraction, and as all refraction (in proportion to its degree) decomposes light, it is therefore apparent that chromatic aberration could not be destroyed if all refracting substances *made equal separation of the colors*; and it was Newton's impression that they did, and therefore he abandoned all further exertions of improving refracting telescopes, but fortunately for the cause of science, he was in error; all refracting sudstances bo not equally *disperse* the prismatic colors at the same degree of mean refraction.

For instance, *crown glass*, whose index of refraction is 1,51
and dispersive power - - - ,033
And flint glass, whose index of refraction is - 1,58
and dispersive power - - - ,050

can be worked into a compound lens refracting no color. Such a lens is called an *achromatic lens*, the converse term of *chromatic*, pertaining to color.

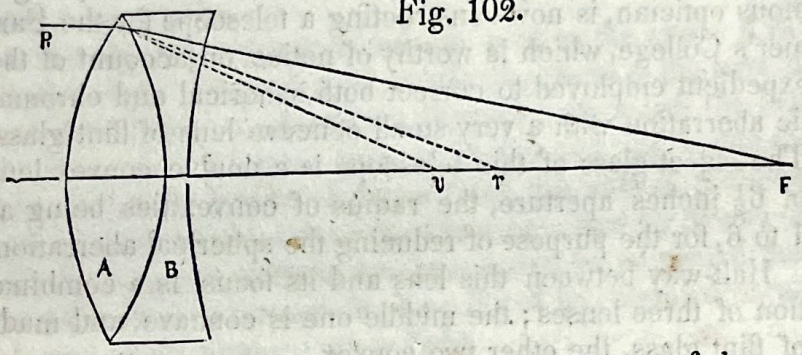
By inspecting the above figures, we perceive that the two kinds of glass refract nearly equal—but when made into prisms, the length of the spectrum from one will be to that of the other as ,033 to ,050, or as 33 to 50. That is, in one case the *violet* ray will be *dispersed* from the *red* 33 lines of measure, and in the other 50.

It can be shown by a mathematical process (too intricate to be presented in a work like this) that *if we combine a common lens of crown glass whose focal distance is* 33, *with a concave lens of flint glass whose virtual focus*

or inverse focal distance is 50, *the chromatic aberration will be destroyed between the extreme rays of the spectrum, the red and violet.*

We give merely an occular explanation of this by Fig. 102.

Fig. 102.



Let A represent a convex lens, and R one of the extreme parallel rays; by the action of this single lens the violet rays would make their focus at v, and the red at r. But by the action of the concave lens B, the rays v and r are refracted the other way towards the parallel or original direction; and the violet ray v is more refracted than the red ray r: and the concavity of B is just sufficient to throw them together: and when thus thrown together the united rays still converge towards the axis, and will form a focus in F.

It is plain that if the concavity of B was equal to the convexity of A, the refracted rays would then be parallel, the same as before they met either lens, but in that case the violet ray v would be refracted above the *red* ray r, because the dispersive power of the glass B is greater than that of A; hence this compound lens still acts as a convex lens, and is *achromatic*.

Let the distance from the lens to its focus be represented by x, then its value may be found by the equation

$$\frac{1}{x}+\frac{1}{50}=\frac{1}{33}$$

Therefore $x=97{,}06$

This compound lens is not in fact perfectly *achromatic*, for the two kinds of glass do not give uniform proportionality of colors, and although the extreme rays, the violet and the red, are made to unite, yet all the other colors will

not exactly unite, and this discrepancy is called *irrationality of dispersion.*

This correction for chromatic aberration corrects also for spherical aberration very nearly.

(Art. 118.) Mr. B. Hasart, of Cincinnati, a very ingenious optician, is now constructing a telescope for the Farmer's College, which is worthy of notice, on account of the expedient employed to correct both spherical and chromatic aberration with a very small concave lens of flint glass. The object-glass of this telescope is a double convex lens of $6\frac{1}{2}$ inches aperture, the radius of convexities being as 1 to 6, for the purpose of reducing the spherical aberration.

Half-way between this lens and its focus, is a combination of three lenses; the middle one is concave, and made of flint glass, the other two convex.

The diameter of these lenses is only $3\frac{1}{4}$, owing to their nearness to the focus of the object lens. The combined curvatures of these lenses are so arranged as to correct spherical aberration; at the same time the excess of the *dispersive power* of the concave flint lens corrects chromatic aberration.

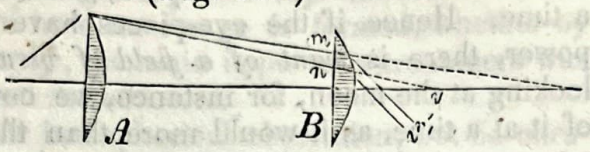
If this succeeds it will be a great triumph, for a piece of *pure* flint glass, of 3 or $3\frac{1}{4}$ inches in diameter, will not cost one-tenth part as much as a perfect specimen of ten inches in diameter, and it is even difficult to obtain the latter at any price whatever. The success of this telescope will surmount the 5th difficulty.

(Art. 119.) We have now perfected the telescope as far as its principal focus, where the image is formed. We must now magnify this image by a microscope, which microscope will have both *spherical* and *chromatic* aberration, if it consists only of a single lens; to avoid these defects, we must have what is called—

AN ACHROMATIC EYE-PIECE.

Achromatic eye-pieces can be made on the same principle that we have employed in making object-glasses; but such eye-pieces are never used, because the color can be corrcted, *for short focal distances*, in a superior manner, by a proper arrangement of simple lenses of the same kind of glass.

(Fig. 103.)



This arrangement is shown in (Fig. 103.) where A and B are two plano convex lenses, A being nearest the object glass, and B the one next to the eye. A ray of white light is represented as passing through the lens A, and the colors are separated; the violet ray meets the lens B, at n, and is again refracted; the red ray meets the lens B at m, a greater distance from the axis of the lens, and is *more refracted* than the violet ray; and by means of an adjusting screw, these two lenses can be so placed that the colored rays through the lens B will be refracted parallel, and again produce white light.

With this eye-piece the refracting telescope is now complete—a most efficient and important instrument, one which required the perseverance of ages, and the combined power of science and art.

(Art. 120.) With an eye-piece, as described in the last article, the object appears inverted, which, for astronomical purposes, is a matter of little or no inconvenience; but for terrestrial purposes it is objectionable, as the inverting of objects to most persons is perplexing and troublesome; and to avoid this, there is now constructed an *erecting eye-piece*, consisting of four lenses, two of them are for the sole purpose of erecting the image; but by repeated refractions light is lost, and for that reason the erecting eye-piece is never put in an astronomical telescope.

(Art. 121.) Both spherical and chromatic aberration can be *nearly* avoided by using object glasses of very small aperture, very thin, and of great focal length; but this would render the instrument inconveniently long, and the small aperture would not admit sufficient light—therefore, when we go to extremes to avoid one difficulty we fall into another.

We can have the same magnifying power by taking a shorter focal length for the object glass, and then applying a higher microscopic power to the image; but when we apply a high microscopic power to an object, the focal length of the microscope must be short, and of course the

object small, or but a small portion of it can be viewed at a time. Hence, if the eye-pieces have great magnifying power, there is *want of a field of view*, and if we were looking at the moon, for instance, we could see but a part of it at a time, as it would more than fill the field of the telescope, and the light would be proportionally weakened.

Lastly, if we make a telescope of sufficient aperture to admit light, and of a focal length not to be inconvenient, and of a magnifying power to have a sufficient field of view, then we require the utmost skill in the artist to adjust its parts, and to avoid all the difficulties of aberration, &c. and render the instrument as perfect and efficient as possible; but unhappily there is no perfection attending human art, and on this point we quote the words of Sir John Herschel, lest we might be charged with extravagance:—

"Human hands," says he, "or machines, never formed a circle, drew a straight line, erected a perpendicular, nor ever placed an instrument in *perfect* adjustment, unless accidentally, and then only for an instant of time. This does not prevent, however, that a great approximation to all these desiderata should be attained."

(Art. 122.) As a concentration of the truths we have endeavored to teach, we will now briefly recapitulate—

1st. A single lens may be a microscope or a telescope, according to its focal length. If the focal length is less than the distance of distinct vision, (5 or 6 inches,) then it is a microscope—if greater, then it is a telescope.

2d. When a second lens is used to magnify the image formed by another lens, the instrument is a *compound* telescope, or a *compound* microscope, according to the focal length of the object glass.

Hence, it will be perceived that there is no difference in fundamental principle between a telescope and a *compound* microscope.

3d. The magnifying power of a telescope is formed by dividing the focal length of the object-glass by the focal length of the eye-glass.

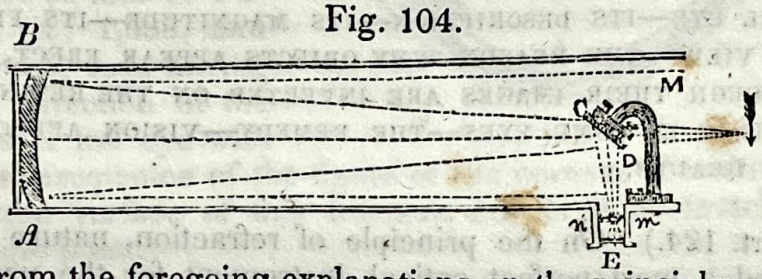
(Art. 123.) We have already devoted much space to telescopes; but it is important that we should explain the principle of making *reflectors*.

It will be recollected Art. 94, that concave mirrors

were capable of forming images of objects in the air, and as it is no matter how an image is formed, whether by *refraction* or *reflection*, the main hope of astronomers was at one time centered in reflectors.

A concave mirror has spherical aberration, but no chromatic aberration. The spherical aberration would be destroyed by giving the mirror an elliptical shape for near objects, and a parabolic shape for very distant objects; but as these figures are very difficult to attain, opticians have contented themselves with mere spherical mirrors.

Fig. 104.



From the foregoing explanations on the principles of reflection and refraction, the Newtonian reflector will be understood by its representation (Fig. 104,) where *AB* represents a convex mirror; *mn* its inverted image; *CD* is a small plane mirror, set at an angle of 45 degrees to the axis of the telescope, to receive the image and reflect it to the microscopic eye-piece at *E*. This telescope is not quite satisfactory to persons unacquainted with optical science—for it would try their tempers and trouble their imaginations to see the moon by looking into the side of a tube when they knew it was in a line with the tube.

Perhaps it was this consideration that caused Gregory to place the small mirror *CD* directly facing the large one *AB*, and then making an orifice in *AB* to admit the eye-piece. The spectator then views the image in *CD* in the same direction as if it were the real object; and it would be difficult to convince the uninitiated that he had not the real object in view.

A telescope constructed as last described is called the Gregorian telescope, and is the kind of reflector most in use. There are several other kinds of reflectors, but they are all on the same general principle, and bear the names of their different modifiers.

The reflecting telescope is very good for viewing the moon and the larger planets, when there is sufficient light but in consequence of so much light being lost by reflection, this instrument is far inferior to the refracting telescope, for viewing the fainter astronomical objects, and for the general wants of astronomy.

CHAPTER VII.—A PERFECT OPTICAL INSTRUMENT, THE ANIMAL EYE—ITS DESCRIPTION—ITS MAGNITUDE—ITS FIELD OF VIEW—THE REASON WHY OBJECTS APPEAR ERECT, ALTHOUGH THEIR IMAGES ARE INVERTED ON THE RETINA—DEFECT IN SOME EYES—THE REMEDY—VISION AFFECTED BY HEALTH.

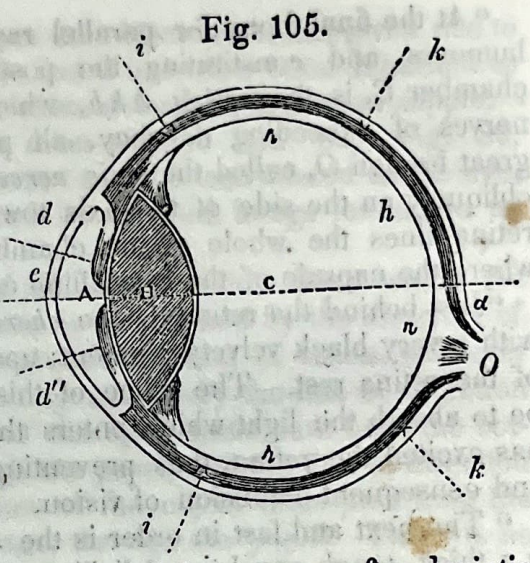
(Art. 124.) On the principle of refraction, nature has formed a most perfect optical instrument for the use to which it is applied, the *animal eye*, and for its description we shall mostly follow Bartlett.

"The eye is a collection of refractive media, which concentrate the rays of light proceeding from every point of an external object, on a tissue of delicate nerves, called the retina, there forming an image, from which, by some process unknown, our perception of the object arises. These media are contained in a globular envelope composed of four coatings, two of which, very unequal in extent, make up the external enclosure of the eye, the others serving as lining to the larger of these two.

"The shape of the eye is spherical, except immediately in front, where it projects beyond the spherical form, as indicated at *d e d''*, (Fig. 105,) which represents a section of the human eye through the axis in a horizontal plane. This part is called the *cornea*, and is in shape a segment of an ellipsoid of revolution about its transverse axis which coincides with the axis of the eye, and which has to the conjugate axis, the ratio 1,3. It is a strong, horny, and delicately transparent coat.

"Immediately behind the cornea, and in contact with it, is the first refractive medium, called the *aqueous humour*,

Fig. 105.



which is found to consist of nearly pure water, holding a little muriate of soda and gelatine in solution, with a very slight quantity of albumen. Its refractive index is found to be very nearly the same as that of water, viz: 1,336, and parallel rays having the direction of the axis of the eye will, in consequence of the figure of the cornea, after deviation at the surface of this humour, converge accurately to a single point.

"At the posterior surface of the chamber *A*, in contact with the aqueous humour, is the *iris*, *g g*, which is a circular opaque diaphragm, consisting of muscular fibres by whose contraction or expansion an aperture in the center, called the *pupil*, is diminished or increased according to the supply of light. The object of the pupil seems to be, to moderate the illumination of the image on the retina. The iris is seen through the cornea, and gives the eye its color.

"In a small transparent bag or capsule, immediately behind the iris and in contact with it, closing up the pupil and thereby completing the chamber of the aqueous, lies the *crystalline humour B*; it is a double convex lens of unequal curvature, that of the anterior surface being least; its density towards the center is found to be greater than at the edge, which corrects the spherical aberration that would otherwise exist; its mean refractive index is 1.384, and it contains a much greater portion of albumen and gelatine than the other humours.

"The posterior chamber *C*, of the eye, is filled with the *vitreous humour*, whose composition and specific gravity differ but little from the aqueous. Its refractive index is 1,339.

"At the final focus for parallel rays deviated by these humours, and constituting the posterior surface of the chamber *C*, is the *retina h h h*, which is a net-work of nerves of exceeding delicacy, all proceeding from one great branch *O*, called the *optic nerve* that enters the eye obliquely on the side of the axis towards the nose. The retina lines the whole of the chamber *C*, as far as *i i*, where the capsule of the crystalline commences.

"Just behind the retina is the *choroid coat k k*, covered with a very black velvety pigment, upon which the nerves of the retina rest. The office of this pigment appears to be to absorb the light which enters the eye as soon as it has excited the retina, thus preventing internal reflection and consequent confusion of vision.

"The next and last in order is the *sclerotic coat*, which is a thick, tough envelope *d d' d''*, uniting with the cornea at *d d''* and constituting what is called the white of the eye It is to this coating that the muscles are attached which give motion to the whole body of the eye."

"The total length of the eye is about 0.91 of an inch; the principal focal distance of the lens is 1,73; and the range of the moving eye-ball, or the diameter of the field of distinct vision, is 110°. The field of vision is 50° above a horizontal line, and 70° below it, or altogether 120° in a vertical plane. It is 60° inwards, and 90° outwards, or altogether, in a horizontal plane, 150°."

(Art. 125.) From the foregoing description of the eye, (it being a lens and capable of forming images,) and from its comparison to a camera obscura, or darkened chamber, (Art. 84,) it will be readily admitted that images are formed on the retina in an inverted position; but if this should be doubted we can have occular demonstration by the following experiment:

Procure the eye of any recently killed animal, as an ox, for instance, and with a sharp knife pare off its posterior coats until transparency begins to appear; place the eye thus prepared in an orifice of a window-shutter to a darkened room, and place small objects before it; the images of such objects will be distinctly seen inverted on the retina, or in the back part of the eye.

The fact that inverted images are formed on the retina,

and we nevertheless see the object erect, has given rise to much discussion, for in fact it has often been regarded as a paradox; but truth, when arrived at, is always simple.

To explain this, we must refer to Art. 84, Fig. 80, where the dark chamber may be considered as the eye, the spire the object, and its inverted image the image on the retina.

Now the *locality* of all objects which come within the cognizance of our vision is determined by the *direction* of the ray of light which strikes the seat of vision, wherever that may be. This being admitted; the line of direction which *locates* the top of the spire must pass from the bottom of the eye through the *pupil*, and the line of direction which *locates* the bottom of the object must pass from the top of the eye, or image, through the *pupil*. There is no feeling of the imprint of an image on the retina, and we can conceive the top of this spire to be in no other direction than somewhere in the direct line towards it, and the same may be said of the bottom; and thus an *inverted image* must necessarily give an *erect object*.

(Art. 126.) We have said that the eye was a perfect optical instrument, and this is true in general, but not in every particular case.

With age, the cornea loses a portion of its convexity, and its refracting power is in consequence diminished, and distinct images are no longer formed on the retina. Persons with such eyes are said to be *long-sighted*, because their distance of distinct vision is increased. The remedy for this defect is, of course, a *convex glass*, which restores the former degree of refracting power, and with it distinct vision.

The opposite defect is very common in young persons—a too great convexity of the cornea, and, of course, its too great refracting power; the image is formed not on the retina, but in front of it. Such persons are said to be *short-sighted*, for they can see objects but at a very short distance. The remedy, of course, is *concave glasses*.

(Art. 127.) To possess perfect vision, it is not only necessary that the eye itself should be perfect as an optical instrument, but that the optic nerve which comes from the brain should be in a perfect and healthful state. Anything

that deranges the brain affects the vision; a person with a headache has very imperfect sight. A man intoxicated has a nervous brain, the optic nerve has a slight tremulous motion which causes all objects to appear to him as unsteady and tremulous.

CHAPTER VIII.—COMPOUND MICROSCOPES—TELESCOPES AND MICROSCOPES COMPARED—THE MAGIC LANTERN—SOLAR MICROSCOPE—PERSPECTIVE GLASS—BURNING GLASSES.

(Art. 128) Those who have attended to the subject matter of the foregoing chapters on optics, will at once understand all that is to follow. The fundamental principles of *refraction* and *reflection*, and the manner of forming images of objects, have been fully explained, and all who understand the explanations will at once comprehend any optical instrument by the mere inspection of its parts.

In a preceding chapter, we have several times incidentally mentioned a *compound microscope*; but we have given no formal description of it. A compound microscope consists of two or more *convex lenses* of considerable convexity and short focal distance, used for magnifying small objects which are close at hand.

The object lens of a microscope is smaller than the eye lens, and the inverted image formed by the object lens is farther from the lens than the object, and is as much larger as it is at a greater distance. The eye-glass magnifies this image as though it were a real object.

The magnifying power of a microscope is estimated thus:—First, suppose the image is five times the distance of the object from the object lens, it is then magnified five times in linear measure, or twenty-five times in superficial measure. Secondly, suppose the focal length of the eye-glass is only one-half an inch, and the limit of distinct vision six inches, then the magnifying power *on the image* is twelve in linear measure, and one hundred and forty-four in superficial measure, and the object is magnified 5×12 or 60 times in direct length or diameter, and 25×144 or 3600 times in surface.

(Art. 129.) In the telescope, we have seen that large objects at a great distance, (men and planets, for example,) gave small images at the focus of the object-lens; and in the microscope a small object near by gives an enlarged image at a greater distance, and on this principle the image may be so large that it would not be practicable to apply a magnifying glass to it, and when this is the case we have the *magic lantern* and the *solar microscope*.

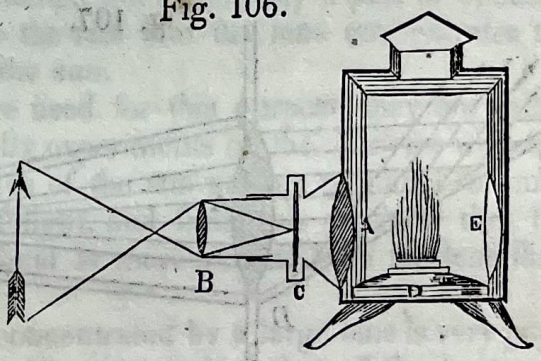
When a very large image of a very small object is attempted, it is evident that the image must want light to render it visible, and this light must be furnished by artificial means—and the means employed is a lamp with the magic lantern, and the light of the sun with the solar microscope.

But we will more particularly describe these instruments, commencing with the

MAGIC LANTERN.

"This consists of a small close chamber, (Figure 106,) from one side of which proceeds a tube containing usually 2 convex lenses *A* and *B*, with an intermediate opening for a glass slide *C* which may be moved freely in a direction at right angles to the common axis of the lenses. Within the chamber is an Argand lamp *D*, behind which is a concave reflector *E*. The rays proceeding from any point in a figure, painted with some transparent pigment upon the glass slide and strongly illuminated by the lens *A* upon which the direct light from the lamp, as well as that from the reflector *E* is concentrated, will be brought to a focus by the lens *B*, a short distance in front of the instrument; here the rays being reflected will proceed as from a new radient, and a magnified image of the figure will thus appear upon the screen. Should the screen be partially

Fig. 106.

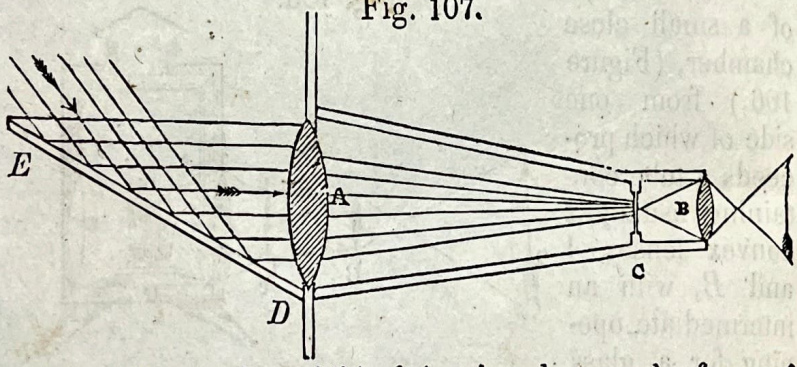


transparent, a portion of the rays will be transmitted, and the image will be visible to an observer behind it.

"The linear dimensions of the object or figure will be to those of the image, as their respective distances from the lens *B*; if, therefore, the lens *B* be mounted in a tube which admits of a free motion in that containing the lens *A*, its distance from the figure may be varied at pleasure, and the image on the screen made larger or smaller; the instrument, at the same time, being so moved as to keep the screen in the conjugate corresponding to the focus occupied by the glass slide. The instrument, with an arrangement by which this can be accomplished, is called the *phantasmagoria*. In order, however, that the deception may be complete, there must be some device to regulate the light, so that the illumination of the image may be increased with its increase of size, not diminished, as it would be without such contrivance.

SOLAR MICROSCOPE.

Fig. 107.



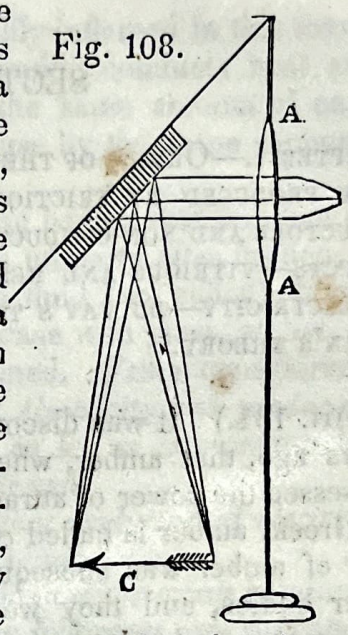
The object to be exhibited is placed near the focus of the illuminating lens *A*, so as to be perfectly enlightened and not burnt, which would be the case were it at the focus.

This is the same as the magic lantern, except that the light of the sun is used instead of that from a lamp. *DE* (Fig. 107,) is a long reflector on the outside of a window shutter, in which there is a hole occupied by the tube containing the lenses.

(Art. 130.) We have a very simple and instructive application of the single microscope in the perspective glass, represented in Fig. 108. It consists of a large concave lens *AA*, and *BB*, placed at an angle of 45° from a perpendicular, to receive the rays of horizontal objects

and reflect them into the face of the *lens* which magnifies them, and they appear in a horizontal direction. When the object is a landscape painting, a distant city, or buildings drawn in conformity with the principles of perspective, and the lens is set in the side of a large box, in the side of a room concealing the view and the real size of the picture, the effect is very striking and pleasant. Such views are very attractive in *shows* and *museums*, and it is not too much to say that they greatly astonish those who are not acquainted with the principles of optics.

Fig. 108.



(Art. 131.) Although not technically a part of optics, it is proper to notice the fact that the lens concentrates the heating power of the sun.

When lenses are used for this purpose they are called *burning glasses*. By experiments on the *spectrum* we learn that the heating rays of the sun are not refracted so much as the red rays of light, and from this we infer that the greatest focus of heat is more remote from the lens than the focus of light.

The solar heat concentrated by a large lens is very powerful, and is said to be greater than that of the best constructed furnace; but its utility is of course very limited, on account of its application to but a little more space than a mere point.

Few substances can withstand the focus of a large burning glass—brick, slate, and other earthy matters are made to boil; metals melt, and some of them are soon volatilized away.

SECTION V.

CHAPTER I.—ORIGIN OF THE TERM ELECTRICITY—ELECTRICITY PRODUCED BY FRICTION—CONDUCTORS—PARTIAL CONDUCTORS AND NON-CONDUCTORS—OPPOSITE ELECTRICAL EFFECTS—VITRIOUS AND RESINOUS, POSITIVE AND NEGATIVE ELECTRICITY—DU FAY'S THEORY OF ELECTRICITY—FRANKLIN'S THEORY.

(Art. 131.) It was discovered, more than two thousand years ago, that amber, when rubbed with silk or woolen, possessed the power of attracting and repelling light bodies. In Greek, amber is called *electron*, and this singular property of amber was subsequently discovered to belong to other bodies, and they were in consequence associated with amber, (*electron*,) and those bodies possessing this property were called *electrics*, and the *attractive* and *repulsive* property itself was called *electricity*.

From that time to the present nearly every substance has been experimented upon, and all substances that possess the power of attraction and repulsion after being rubbed, are called *electrics*—those that do not possess this power are called *non-electrics*.

The most prominent electrics are—glass, resin, sulphur, silk, sealing wax, furs generally, and dry woolen cloth.

Many substances are partial or poor electrics—and by far the greatest number of substances are *non-electrics*; metals are non-electrics.

What electricity is we know not—we only know its action, its effects; but whether it is, as many suppose, an independent and self-existing fluid, or two fluids, or whether it is a peculiar operation of *caloric*, or a mere property of bodies like gravity, we cannot tell—but recent investigations show that it is very intimately connected with light and heat.

Heat is produced by friction.

Electricity is produced by friction.

It is well known that violent friction will inflame most combustibles. Very dry wood that is not a conductor of

heat is comparatively very readily inflamed in this manner, and very green wood which rapidly conducts heat away, cannot be inflamed, although the same amount of caloric may be produced in either case by the same amount of friction.

So it is with electricity—those bodies that conduct *electricity* do not show the electric property after friction, and those that do not conduct the fluid (so called) show the electric power, and this is the case with glass, amber, silk, sulphur, &c., as before mentioned. From considerations like these, it was inferred that *electricity was produced by the friction of all bodies*, and as far as experiments have gone, the theory has been confirmed.

(Art. 132.) All bodies are either *conductors of electricity*, *partial conductors*, or *non-conductors*.

To give a clear and definite idea concerning conductors and non-conductors, we cite the following experiments:

Take a glass tube, and by means of a cork, insert a wire or metalic rod into one end of it. Now if the tube be dry and rubbed with dry silk, not only the space rubbed possesses the power of attracting and repelling small pith or cork balls suspended by fine threads of dry silk, but the wire or metalic rod will possess the same power also. If the tube be terminated by a rod of glass or sealing wax, in place of the wire or metalic rod, or a metalic ball be suspended from the tube by a thread of silk, nothing but the tube will possess the electric influence—it does not pass along the glass or wax bar, or down the silk thread, as it did along the metalic wire; thus some substances are found to be *conductors*, others *partial or poor conductors*, and others *non-conductors*.

If all substances conducted electricity, we should probably have no knowledge of its existence, for it would be conducted away as fast as it could be excited.

When a body is entirely surrounded by non-conductors, it is said to be *insulated*. As dry air is a non-conductor, and glass also a non-conductor, a person standing on a glass stool would be *insulated*, and any substance standing on glass or sealing wax or sulphur would be insulated.

We have asserted that the friction of all bodies produce electricity. Non-conductors at once show electricity, when

friction is applied by other non-conductors. Of course, conductors cannot show electricity, as it is instantly conducted away; but when a conductor is *insulated*, such as a bar of iron, or brass, or steel, set in a glass handle and the other end terminated in glass, and then friction applied by a non-conductor or by another insulated body, then we have electricity the same as by an electric. It is true, all bodies have not thus been subjected to experiment; but, as far as experiments have gone, this has been the uniform result. Therefore, we say—*electricity is produced by the friction of all bodies.*

(Art. 133.) *The same body produces opposite electrical effects—first attraction, then repulsion.*

Suspend a feather, or small piece of cork or pith ball by a fine thread of silk, and approach it with a glass rod just after it has been rubbed with silk or fur: the feather or ball will be first attracted to the glass, then it will fly off, and in whatever position the glass is placed the suspended body will recede from it or make efforts to get away, and this is called repulsion.

(Art. 134.) If glass or *vitrious* electrics, and sulphur or *resinous* electrics are excited, they will show opposite effects in the same time.

Suspend a feather, or any other light substance, as mentioned in the last article, and apply an excited stick of sealing wax or roll of sulphur, and when the substance is repelled by the glass it is attracted by the wax—*in short, the glass and wax always have an opposite effect.* This has created the terms, *vitrious* and *resinous* electricity.

From these facts, a French philosopher, *Du Fay*, assumed the hypothesis that *two* electric fluids exist in nature, the *vitrious* and *resinous*—that they mutually attract and neutralize each other; but the particles of the same fluid are self-repellant; that in all unelectrified bodies these two fluids are in a neutral and combined state, and that when a body was electrified it was in consequence of a superabundance of one or the other of these fluids.

Dr. Franklin supposed there was but *one* electric fluid, which pervades all bodies in a natural state, but on the application of friction bodies may be made to contain more or less than in their natural state, and then we say they are electrified.

When a body contains more than its natural quantity, it is said to be *positively electrified;* when less than its natural quantity, it is said to be *negatively electrified.*

The *vitrious* electricity of Du Fay corresponds with the *positive* electricity of Franklin, and the *resinous* of Du Fay to the *negative* of Franklin.

Both of these theories have advocates—some adopt one theory, some the other, and either one will about equally well accord with experimental facts; and in the present state of the science, while we know so little of the real existence of what we call electricity, it appears impossible to establish the one or overthrow the other; we shall, therefore, advocate neither theory, but simply state facts.

When the electrics are rubbed together, one acquires *positive*, the other *negative*, electricity. Smooth glass, when rubbed with silk—the glass has positive electricity, and the silk negative; but rough glass, rubbed with silk—the glass has *negative* electricity, and the silk *positive.* Feathers become negative, when rubbed with the fur of a cat, smooth glass, or woolen cloth; but positive, when rubbed against dry paper, silk, fur, or rough glass.

All we can infer from this is, that the rubber and the body rubbed will have different states of electricity, and prior to experiments we cannot say which will have the *vitrious* electricity, for we observe that even glass itself does not always have the vitrious or *positive* kind. These facts favor Franklin's theory; yet some authors, who ought to be considered authority, say that Du Fay's will account for a *greater number* of facts than Franklin's.

(Art. 135.) When the atmosphere is very dry it is a non-conductor of electricity, and at such times we may observe almost spontaneous effects of electricity; the least rubbing of a cat's back with the dry hand will produce electric sparks. When taking off silk and woolen apparel, sparks have been known to come from them, accompanied with a snapping noise. Electricity shows itself on the grandest scale in passing from the earth to the clouds, and from cloud to cloud, as is often exhibited during a thunder storm; but this will be treated of in a future chapter.

CHAPTER II.—ELECTRICAL MACHINES—CYLINDER AND PLATE MACHINES—DIFFICULTIES IN MAKING A MACHINE OPERATE—ELECTRICAL EXPERIMENTS—THE ELECTROSCOPE—CONDUCTING AND NON-CONDUCTING BODIES—ELECTRICAL BELLS.

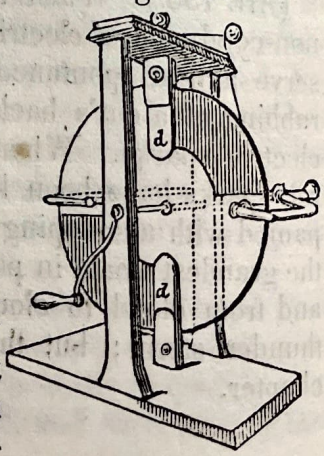
(Art. 136.) The most simple electrical machine is a glass rod or roll of sulphur, and no machines, however great, differ in principle from these—at least so far as exciting the fluid is concerned; larger machines have more appendages for conducting the fluid away, and experimenting with it.

There are two principal forms under which electrical machines appear—the cylinder, and the plate machine.

The former consists of a glass cylinder, made to revolve on its axis with a rubber pressing against it on one side, and metalic points coming very near the glass on the other, to take the electricity excited and convey it unto an insulated metalic body called the prime conductor.

The cylinder should be covered by a silk apron from the rubber to the metalic points on the opposite side, to prevent the electricity being dissipated through the dust in the air. To make an efficacious machine, it should be as near perfect as possible—the cylinder should revolve on a perfect center, be uniformly pressed by the rubber, the frame should be of hard baked wood and covered with varnish to weaken its conducting power; the cylinder, the rubber, and prime conductor must all be insulated; and then, when necessary, communication may be made from the rubber to the prime conductor, or from the rubber to the ground, by means of a chain.

Fig. 109.



The plate machine is represented in Fig. 109. The large cirular plate is of glass; it is pressed by two rubbers *d* and *d*, one above, the other below, as represented in the figure. The prime conductor is a metalic bar, nearly horizontal with the center, and passing on both sides of the plate, and from it many points pass near the glass to collect the electricity as it is evolved from the rubbers. The prime conduc-

tors, of course, must be insulated. Of these machines the latter is thought to be the most powerful; but the former is less expensive, and less liable to crack and get out of repair.

The rubbers of electric machines, where they meet the glass, should be covered with an amalgum of zinc, antimony, and mercury, put together at near a boiling heat, and in such proportions as to be capable of being made into stiff paste with lard.

(Art. 137.) Young operators in electrical experiments frequently bring out their machine, and, to their astonishment and vexation, discover that it is almost powerless and ineffective, and, not fully understanding the difficulties of the case, are very likely to become discouraged in their experimental attempts.

The weather has very much to do with the matter;—when the atmosphere is damp it becomes a partial conductor, or rather the watery vapors of the atmosphere conduct the electricity away nearly as fast as it can be excited.

Whatever is a conductor to electricity is more silently and rapidly so by being presented in small points. Electricity will pass off rapidly and quietly when it finds sharp pointed wires, when a metalic ball placed at the same distance will not take it; and when it does go to a ball it seems to pass with difficulty, and at one bound, attended by a spark and an explosion. Now the *dust* in the atmosphere, particularly the dust of a damp room, is a conductor to electricity, and a conductor in the very best form—a conductor presenting a multitude of sharp points; and, therefore, when a room is damp and dirty, and dusty, it is impossible to make an electric machine operate therein in a satisfactory manner.

To ensure success, then, the machine and the room must be *dry*, *warm*, and, as much as possible, *free from dust*—conditions almost impossible to attain in a schoolroom. But we say to the operator, be not discouraged—for perseverance in drying, warming, and dusting, will ensure, at least, partial success.

(Art. 138.) When the electrical machine is in good condition a great number of instructive and amusing experiments may be made with it; but they are all accounted for on the general principle of attraction and repulsion.

On turning the machine, electricity is evolved, which shows itself in vivid sparks passing to the prime conductor, and if the prime conductor is insulated, it is soon filled or charged with all it can contain, and the surplus passes off into the air, or the machine ceases to evolve; but when a chain passes from the prime conductor to the ground, and another from the rubber to the ground, and the machine turned, a constant stream of electricity is passing through the machine, without accumulating anywhere.

When the machine is in operation and the prime conductor insulated, on approaching it by a knuckle or a finger, vivid and even painful sparks pass to the hand, giving small electrical shocks.

If a person stands on a stool with glass legs, and puts his hand on the prime conductor, he then becomes insulated, and *is*, in fact, a part of the prime conductor; and on turning the machine, electricity accumulates over his body silently and insensibly, unless the machine is very powerful; then he may feel a slight sensation about his head and face, and if his hair is dry and fine it will rise on the principle of repulsion, and thus the person may appear as in an extremity of passion or of fright.

On approaching the prime conductor with a finger or knuckle, we receive a spark or shock, and now, as the person is part of the prime conductor, approach his face and we receive the spark and shock from him, and he experiences the same shock, different only in proportion to the sensibility of the part of the body from which it is taken.

A little alcohol put in an iron spoon, and the electric spark passed through it, will be inflamed. The spark may be made to pass through it by holding the spoon under the knob of the prime conductor, or by letting the spark pass from the finger to the bottom of the spoon by a person standing on the insulating stool. This experiment is very striking, when a piece of ice or icicle is used in place of the finger to carry the spark. All light combustibles can be inflamed in this manner. A mixture of common air and hydrogen gas, put in a gas pistol, can be exploded by passing a spark through it; but this experiment may excite a little alarm in a class.

(Art. 139.) For some experiments we require the use

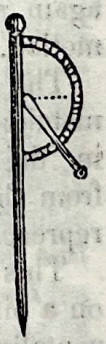
of an *electrometer*. An electrometer or an electroscope, is any instrument to show the presence of electricity—a pith ball or a feather suspended by silk is an electrometer, and the degree of its repulsion from any excited body indicates the degree of electricity.

For very delicate experiments, the gold-leaf electrometer, as represented in Fig. 110, is mostly used. It consists of a brass cap and a connecting wire, which passes through an orifice into a glass vessel, and terminates in two strips of gold-leaf.—When an electrified body is brought near the brass cap, the two strips of gold-leaf diverge, because bodies electrified alike repel each other. Gold-leaf is used on account of its good conducting power and extreme flexibility. The glass case is put over to protect the experiments from disturbance by currents of air. This instrument is so sensitive that the gold leaves have been seen to diverge, by bringing an excited glass tube within *five feet* of the brass cap.

Fig. 110.

For common experiments, we have the quadrant electrometer, as represented in Fig. 111. The stem is made of wood, and the semi-circle commonly of ivory, and its lower half divided into ninety degrees; from the center of the semi-circle hangs a rod of light wood, terminated with a cork or pith ball, to serve as an index. This instrument, when placed upright in the prime conductor and the machine put in operation, the index rises, being operated upon by repulsion. The greater the number of degrees that the index can be driven out the greater the quantity of electricity evolved; but the quantity is by no means in a numerical proportion to the number of degrees passed over by the index. The index may sometimes be driven out to the horizontal, but it can never be made to rise higher.

Fig. 111.



(Art. 140.) *By the motions of the electrometer, we decide the relative conducting power of bodies.*

When the machine is in good condition, and the electrometer standing in the prime conductor, a turn or two will throw it out; then if we stop turning and the electrometer immediately falls, it shows that the electricity is rap-

idly conducted away by a moist or dusty atmosphere. I should fall but gradually and slowly—and just so rapidly or just so slowly as the electrometer falls the electricity is by some means conducted away.

When the electrometer stands out, if we touch the prime conductor with any metalic rod, it instantly falls, showing that the metalic rods are good conductors.

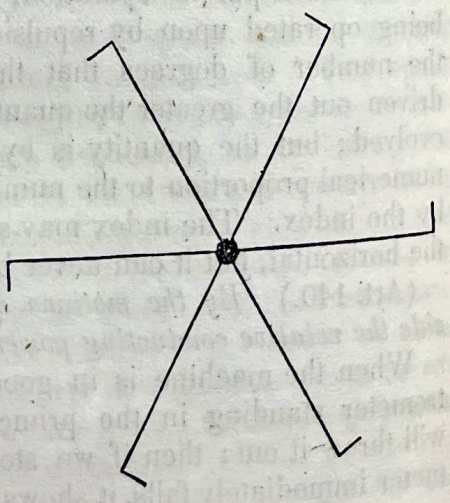
If we touch the conductor with green wood the electrometer falls, but not so quickly as when touched by metal. If touched by dry wood it falls very slowly, and if by glass it scarcely falls at all. These experiments show that metals are conductors, wood partial conductors, and glass a non-conductor; and thus we may experiment on the conducting powers of any substance.

The most amusing experiments, illustrating attraction and repulsion, are the *pantomime dance*, the *fly-wheel*, and the ringing of the *electrical bells*.

To show the pantomime dance, place a few little paper images of men and women on a metalic plate, and bring it under another metalic plate suspended from the prime conductor. The images will be attracted to the upper plate, then repelled to the lower—then again attracted and again repelled, and thus create an agitated and dancing motion.

The fly-wheel is simply a small wheel, consisting of metalic arms branching out from the center, and all bent in the same direction from the extremities, as represented in Fig. 112.

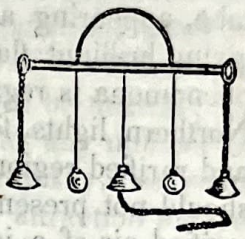
Fig. 112.



This wheel, balanced on a pin, and held horizontally near the prime conductor, the metalic arms will be first attracted towards the prime conductor, and then repelled, as though a fluid run off at the points. The motion is always in a contrary direction from the pointed arms.

The electric bells are shown in Fig. 113. The outer bells are suspended with metalic chains from a metalic bar; the center bell and the two metalic balls are *insulated* by silk thread; from the interior of the center bell a chain passes to the table, floor or ground, to carry off the electricity.

Fig. 113.



The whole is suspended on some portion of the prime conductor. The machine is now put in operation, and electricity runs down the chains to the outer bells. The outer bells now attract the suspended balls, which, in consequence, strike the bells, and are instantly repelled, when they strike the center bell, to which they give their electricity, and it passes off down the chain of the center bell. After the balls strike the center bell, they become in opposite states of electricity to what they were an instant before, and now they will be again attracted to the outer bells, and thus a constant gingle is kept up as long as the machine is in operation.

(Art. 142.) We have more than once remarked, that electricity passed silently, and we may add, unobservedly, along any conducting surface; but let the surface be broken, and the electricity is arrested in the interrupting localities, and shows itself in sparks and slight explosions. This may be shown in a beautiful manner by attaching pieces of tin foil to the surface of glass within short distances of each other, and causing the electricity to pass along the surface. Sparks of light will twinkle along the tin foil, and if the electricity is abundant, and the pieces of tin foil so arranged as to represent images of things, or letters, or words, such images will appear as in a glow of fire. It is, no doubt, the broken passage of electricity from cloud to cloud, and from the clouds to the earth, that causes a similar appearance on a large scale in the heavens.

(Art. 143.) If we have a long glass tube, closed air-tight, with a metalic ball at one end, conveying a wire a short distance into the tube, and the other end furnished with a stop-cock and fitted to an air pump. On exhausting the tube and presenting the ball to the prime conduc-

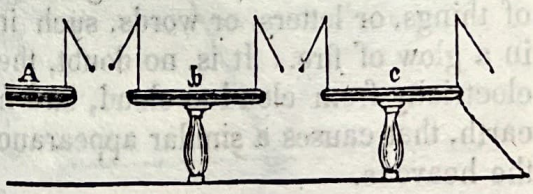
tor, the electricity passes down the whole length of the tube, appearing as a pale milky flame, but now and then giving brilliant flashes when the tube is touched. This phenomena is regarded as a miniature resemblance of the Northern lights, for when the electricity is in the upper and rarified regions of the air, there is no reason why it should not present the same appearance as it does in the rarified air of a jar.

Chapter III.—Electrical induction—the Leyden jar—to charge a jar—the electrical battery—to charge one jar from another—to charge jars negatively—electricity resides on the glass, and not on the coating of a jar—the flash and spark not inherent in electricity.

(Art. 144.) A body may be electrified by being brought near to another electrified body; and in such cases the body is said to be electrified by *induction*. A pith ball brought near to an excited glass rod becomes electrified by induction; but this principle is best illustrated by the following experiments.

Let *A*, (Fig. 114,) represent the prime conductor of a machine, and *b* and *c*, &c. any number of *insulated conductors*, the last one connected to the ground by a conductor or chain.

Fig. 114.



The conductor *b* is electrified by induction from *A*.

The prime conductor of any glass machine is always positively electrified, and by the position of the pith balls we perceive that the opposite ends of *b* are in an opposite state of electricity; so also is *c*, while the centers of *b* and *c* remain neutral.

This phenomenon is explained on the principle of two fluids, thus: *b*, in a neutral state, has two opposite fluids

in combination, the electricity of the prime conductor disturbs this neutral state, attracts the negative fluid and repels the positive. Hence the two ends of *b* will have opposite electrical states, and its center will be neutral; the same explanation will apply to *c* and to any number of such conductors, giving them, as we may say, *two poles*. This experiment more clearly explains attraction and repulsion; a pith ball brought near a prime conductor is at first attracted by its negative electricity, but when that is absorbed by the greater quantity of the opposite kind in the prime conductor, then the ball has only the same kind of electricity as the conductor, and is repelled by it.

(Art. 145.) The principle of induction is most apparent in operations and experiments of the Leyden jar.

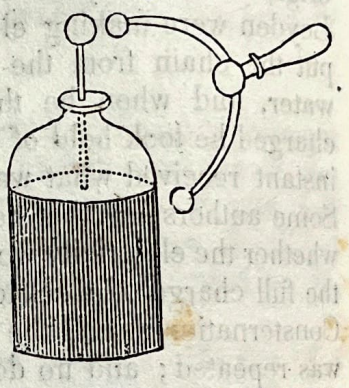
The Leyden jar derives its name from the place of its origin. In the year 1746, while some philosophers of Leyden were making electrical experiments, one of them put the chain from the prime conductor into a glass of water, and when he thought the water was sufficiently charged he took hold of the chain to lift it out, and at this instant received what was then to him a surprising shock. Some authors say that he took the tumbler to drink, to see whether the electricity would affect the taste, and "received the full charge of electricity at the extremity of his nose." Consternation seized the whole company—the experiment was repeated; and no doubt the lively imaginations of the operators greatly heightened the effect, for some very exaggerated reports were spread over the whole country, as to the tremendous effects of the electric shock. A philosopher of Leyden, of much eminence, said, that—

"He felt himself struck in his arms, shoulders, and breast, so that he lost his breath; and it was two days before he recovered from the effects of the blow and the terror; adding, that he would not take a second shock for the kingdom of France." M. Winkler, of Liepzic, testified, that—"the first time he tried the Leyden experiment, he experienced great convulsions by it in his body; and that it put his blood into great agitation, so that he was afraid of an ardent fever, and was obliged to use refrigerating medicines. He also felt a heaviness in his head, as if a stone lay upon it, and twice it gave him a bleeding at the nose."

But, notwithstanding the exaggeration, this was a very important discovery, and at once gave eclat to electricity, and accordingly showmen travelled with electrical apparatus, through the principal cities of Europe, and drew together crowds of spectators—for all were eager to see, and many even had the courage to *feel*, the wonderful experiment.

The imitation of this experiment with the glass of water suggested what we now call the Leyden jar: it was only found necessary to have a glass vessel with electrical conductors on both the inside and out, and *insulated from each other*—the water was the conductor inside of the glass, and the hand that held the tumbler was the conductor on the outside; but better conductors than these are now used.

Fig. 115.



Tin foil, both on the outside and inside of the jar, as represented in Fig. 115, with a wire having a knob at the top and running down to the inside coating of the jar, and a chain round the outside coating to connect it with the ground, constitutes the whole apparatus of the jar. Care is taken not to let the coatings come to the top of the jar, for then they might meet, or come so near as to neutralize each other's electricity.

(Art. 146.) To charge a jar, place the knob in communication with the prime conductor when the machine is in action, and let the chain from the outside be connected with the ground, or, what is better, to the rubber of the machine. The inside of the jar is *positively* electrified by the prime conductor, and the outside is *negatively* electrified by *induction*.

The larger the jar (other things being equal) the greater the quantity the inside coating can receive, and the outside is supposed to take the same quantity of an opposite kind.

Several jars may be connected together by making a metalic communication from one knob to another, which

connects the inside coatings, and connecting also the outside coatings. Such a combination of jars is called a *battery;* but they do not differ in principle from one jar.

(Art. 146.) To discharge a jar, nothing more is necessary than to make a communication (by some conductor) between the outside and the inside coatings of the jar; the two kinds of electricity which have strong attractions for each other, then instantly come together and produce a shock. The discharging rod, as seen by the jar, (Fig. 115,) consists of two metalic rods which open on a center, and attached to a glass handle. The electricity seems to pass along on the metalic part, not coming on to the glass handle, and therefore a person may discharge a jar, or ever so powerful a battery, without experiencing the shock.

A person may use his arms, or thumb and finger, to connect the two coatings—that is, touch the outside coating with one hand and the knob of the jar with the other, then his person will be the discharging rod, and he will receive the shock.

On the same principle, any number of persons, by taking hold of hands, can form a connection between the two coatings, and they will all receive the shock at once. The person at one extremity may take hold of the chain round the outer coating, and the person at the other extremity touches the knob of the jar. By this arrangement, the series of persons correspond in principle to the discharger, or discharging rod.

When several persons receive the shock, some will feel it in the arms, some in the shoulders, some in the back, some in the knees, &c.; and it is supposed that each one receives it in that portion of the body where he is weakest.

When any person or anything is to receive the force of the shock, that person or thing must be in the line of communication between the two coatings after the jar is charged. Thus, if we wish to give the shock to a mouse, the animal must be placed between two wires which touch the opposite sides of his body, the said wires forming the circuit of communication between the two coatings of the jar. With a good electrical machine, and one or two good jars, sufficient electricity may be accumulated to kill small animals; though some animals are easier killed than

others. A discharge from a battery of ten or twelve jars would destroy human life; and young and reckless persons should never be suffered to trifle with a battery.

(Art. 147.) If several jars be connected, so that the outside of one jar conducts to the inside of another, and the knob of the first jar be brought near the prime conductor, and the outside side of the last jar connected to the ground, then all the jars can be charged by the same kind of electricity, on the principle of induction. (Art. 144.)

The inside of the first jar will receive positive electricity, and will *induce* negative electricity on the outside. This negative electricity on the outside of the first jar makes positive electricity in the second jar—and thus the inside of every jar becomes positively electrified; but if the jars are many, the last jars will not be so highly charged as the first, all other circumstances being equal.

As jars are thus electrified by induction, it follows that the thinner the glass the more powerfully the jars can be charged; and this accounts for some small jars being really more powerful than other larger ones; but jars are very liable to break when they are very thin.

A jar may be charged negatively by connecting its interior coating with the rubber, and the prime conductor with the ground.

The amount of electricity held by a prime conductor, or by a jar, depends on the area of surface, *and not on the magnitude or solidity of the body.*

(Art. 148.) A jar in good order will remain charged for several days; but, of course, the time will depend very much on the conducting state of the air—its freeness from moisture and dust. A jar may be silently discharged in the space of a few minutes, by making an approximate communication between the two coatings, by means of sharp points, or hold a charged jar in one hand, and bring a needle near to the knob by the other, and after holding it thus a few moments the jar will be discharged. In this way lightning-rods, armed with sharp points, may quietly discharge electricity from an electrical cloud.

(Art. 149.) As we are compelled to use the coatings to charge a jar, it is natural to suppose that the electricity rests in the coatings; but it is found to reside on the glass,

for if we use *movable* coatings we can first charge the jar, then carefully remove the coatings, and we can handle them, and bring them together and there will be no signs of electricity, and we may put in the *same* or *other* coatings, and then discharge the jar. The coatings only serve to distribute the electricity over the surface of the glass, and when the jar is discharged they serve to bring it all off at once.

(Art. 150.) The flash and spark is supposed by some, not to be inherent in the electricity itself, but the result of a condensation of the air through the space the fluid passes. In conformity to this hypothesis, we find that the spark and report is much less when the discharger is brought at once close in communication with the coatings of the jar, than where the spark is made to pass through a greater distance of air. The greater intensity and brilliancy of the spark in condensed air, and its comparative feebleness and diffuseness in a rarified medium, corresponds also with the same view, and the *zigzag* course of the spark when passing a long distance is well explained by the same theory; for the fluid, in its passage through the air, condenses a body of it, which in turn obstructs the electric fluid, which in consequence darts off to one side, and condenses another body of air as before, and the electricity is again turned off in another direction, and thus its course is changed and changed until it meets the conductor through which it is aiming. The brilliant and zigzag course of lightning is explained by the same theory.

CHAPTER IV.—ELECTRICITY AND LIGHTNING IDENTICAL—ELECTRICAL EXCITEMENT IN STEAM—CHEMICAL CHANGES PRODUCE ELECTRICITY—THUNDER SHOWERS—LIGHTNING RODS—SAFETY IN THUNDER STORMS—ELECTRICITY ON THE YARD ARMS OF VESSELS

(Art. 151.) It was long suspected that the thunders and lightnings in the atmosphere were the same as that developed by an electrical machine, and Dr. Franklin was the first who suggested experiments to prove it. We col-

lect electricity from its source by means of an insulated conductor—therefore, thought Franklin, if a cloud is a source of electricity, we can collect it by means of a tall rod run up into the air, and insulated at the bottom, so the electricity will be held and not instantly conducted off. According to this suggestion, several philosophers of Europe determined on making the experiment.

On the 10th of May, 1752, a bar of iron, forty feet high, which had been previously erected for the experiment, in a garden at Marby, became electrified as a cloud passed over it—"and, during a quarter of an hour, it afforded sparks, by which jars were charged, and other electrical experiments were performed."

About the same time, it is said, similar experiments were made in England.

At this time, Franklin was having a spire erected in the city of Philadelphia, to try the same experiment; but seeing a boy's kite sailing in the air, it suggested a more expeditious method of obtaining the same object. Accordingly, he constructed a kite, and, on the first occasion, raised it in the air. When the rain fell, it wetted the string, and rendered it a good conductor. It was insulated by a silken cord. In short, electric sparks were drawn in abundance, a Leyden jar was charged, and common electrical experiments performed, and the identity of lightning and electricity was fully established.

By the great amount of electricity in the clouds, we readily imagine the danger of making these experiments. They are now discontinued in consequence of the danger. Professor Richman, of St. Petersburgh, was killed by one of these experiments. "He was examining the electrometer, which was standing near the lower extremity of the rod, when stooping a little to look more closely at the phenomena, a large globe of electric fire flashed from the conducting rod to his head and passed through his body, destroying him instantly. A red spot was produced upon his forehead, his shoe was burst open, and a part of his vest singed; his companion was for some time rendered senseless; the door of the room was split and torn off its hinges."

(Art. 152.) We are now to inquire how electricity is

generated in the air, or among the clouds, and fortunately we are not entirely in the dark on that subject.

We have shown that friction was a fruitful source of electricity, and the friction of the air by the different currents of winds may generate atmospherical electricity.

By direct experiment, we know that a volume of steam rushing into the air as from the boiler of a steam engine, excites powerful electricity. When the boiler is insulated, it will attract and repel more powerfully than the prime conductor of an electrical machine; but steam is nothing but the vapor of water, and there are often great volumes of the vapor of water in the atmosphere, and such vapors really make the cloud of the thunder storm, and when such clouds are suddenly and violently driven in one direction by the wind, it is not difficult to account for the demonstrations of electricity. "Violent thunder and lightning is frequently observed in volcanoes and water-spouts."

"We have the authority of two of the most able and accurate philosophers, Lavoisier and La Place, for stating that bodies in passing from the solid or liquid state to that of vapor, and, conversely, in returning from the aeriform condition to the liquid or solid state, give unequivocal signs of either positive or negative electricity.

"Combustion is also attended with the evolution of electricity."

Thunder storms are generally quick and sudden convulsions—soon over, and the electricity is not probably the *cause*, but the *consequence*, of the storm, the consequence of the very *sudden storm*.

In warm weather, and in warm countries, electrical clouds commonly hover over the caps of hills and mountains during the cool of the evening; they are probably drawn thither by the opposite electricities between the mountain and the cloud, and are dispersed when the equilibrium is restored.

Thunder storms commonly move from the west to the east; and we shall show, in a subsequent chapter, that there is reason to suppose that a constant electrical current is passing from east to west.

(Art. 153.) As soon as the identity of lightning and electricity was established, the possibility of defending per-

sons and buildings from the effect of the lightning stroke was apparent.

The fact that a great quantity of electricity would pass along a metalic rod in preference to other bodies, together with the fact that electricity was more readily taken by small pointed bodies than by large and blunt ones, suggested the idea of *lightning-rods*, to extend into the air above a building to take the electricity and convey it safely to the ground. There was much discussion, at one time, whether the top of the rods should terminate by balls or points; but, agreeably to Dr. Franklin's recommendation, points are now universally adopted, as they silently and gradually conduct away the electric fluid. Lightning-rods should extend considerably above the building they are designed to protect, the points should be gilded or silvered to prevent them from rusting; the rod itself may be of iron of half an inch in diameter—but copper is better, it being less liable to oxidize or rust; the lower end should pass some distance into the ground, and turned away from the building, or terminate in a sink or drain of water. A very large building should have two or more rods, for complete protection, for a single rod will only protect a building to twice the distance of its height above the building.

The rod should be confined to the building by wooden fastenings, and well varnished. It would be better to have the rod all in one piece, by welding the bars together; but where this is inconvenient the connection should not be near a fastening, for then a portion of the fluid might take to the house.

Trees are lightning-rods, but not so good as metalic ones, for they are not so good conductors; hence several high trees round a house will protect it from lightning, for the electricity will certainly take one of the trees, if it comes close in the vicinity, and if the trees were not there it would certainly take the house.

Some persons imagine that trees draw the electricity from afar; but this is a mistake—neither trees nor lightning-rods proper, create the fluid, or draw it from a distance, they only take it and conduct it to the earth, when it actually comes within a few feet, or, at most, a few hundred feet of them.

A person in the fields should never take shelter under a tree during a thunder storm, nor should he pass very near high trees, for the very obvious reason that they are conductors. A house on the top of a hill, or any prominent point of land, should always be protected by trees or lightning-rods; and a person should avoid passing over such points during a thunder storm.

As wet wood is a conductor, and dry air a non-conductor, a person in the center of a close room is comparatively safe, for if electricity strikes the house, unless the quantity is very great, it will pass down the outside of the building, especially if the rain has commenced. To keep the air of the room dry, and thus keep out the electricity, it is necessary to close doors and windows when a thunder storm is rising; the middle story is most secure, other circumstances being equal; and a room without a fire-place is more safe than one having a fire-place, especially if warm, and of consequence rarified air, is in the chimney—for rarified and warm air will admit the fluid much more readily than common air.

A person in a dry room and standing on a glass stool, or sitting in a glass chair, is absolutely safe. A person on a feather bed, and the bedstead removed from the wall, is quite safe, absolutely safe if entirely enveloped both head and feet.

It is supposed by many persons that silk garments are a protection against electricity; but it is not so, unless the person is completely *insulated* by them—a partial insulation is worse than none, for then all the shock will pass through the body of the person, and none along the dress.

Barns which have just received the new mown hay are very liable to be struck by lightning, for a gas arises which yields the agreeable odor, and which invites the electricity and determines the locality of the shock; it is therefore very necessary that barns should be protected by lightning rods. The better the conducting power of the rod, the less injury it sustains by an electric discharge; hence a good metalic rod rarely suffers any injury, while trees are frequently torn or riven asunder. Lightning-rods, when very small, or composed of links as a chain, may not conduct a powerful charge with sufficient ease and rapidity, and in

consequence they are severed, and portions of them melted; for this reason, rods should not be very small, and composed of as few links as possible, for at every link, if the iron is rusty, there is a break in the conducting power.

Ships are commonly provided with chain conductors, which they run up above the masts, when occasion may seem to require; but as a general thing, thunder storms are comparatively very unfrequent on the sea, as the humid state of the atmosphere probably keeps up a general equilibriam between the two states of electricity.

Sometimes, however, during stormy nights, the yards become electrified, and the two electrics divide on the same principle as explained in Fig 114, (Art. 144,) and the iron at the yard arms are ornamented with dancing balls of fire. It is commonly difficult to convince the sailors that these are natural phenomena, for in their view these mysterious balls of fire must come from the worlds below, and are connected with lost and wandering spirits; and it is impossible for calm truth to inform or quiet, a troubled conscience and a diseased imagination.

GALVANIC ELECTRICITY.

CHAPTER V.—GALVANISM IS ELECTRICITY OCCASIONED BY UNEQUAL CHEMICAL ACTION ON METALS—ITS THEORY EXPLAINED—DIFFERENCE BETWEEN COMMON AND GALVANIC ELECTRICITY—DIFFERENT KINDS OF BATTERY—THE ELECTROTYPE ART.

(Art. 144.) The term Galvanism is derived from the name of a man (Galvani) who discovered by accident, in the latter part of 1789, that the nerves of a recently killed animal would be convulsed by electricity, and by continuing and varying his experiments he subsequently found that any two metals which corrode unequally would have a similar effect.

At first it was supposed that the animal system had some mysterious agency in the matter; but this was an error;

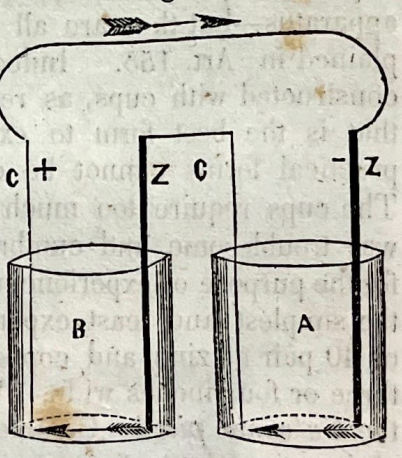
and without stopping to detail even an outline of the many experiments, and the many theories and fancies which this subject occasioned, we at once announce—that *chemical action* on the metals produce electricity.

In the preceding chapters, it was observed that electricity could be produced by friction, and even the metals were electrics when insulated.

We can brighten a piece of copper, brass, or zinc, by rubbing it—that is, by *friction;* but friction produces electricity. However, if we use friction only, we may find it very difficult to make the metal bright; but if we bring to our aid vinegar and salt, or water acidulated with nitric or sulphuric acid, we shall find that much less friction will be necessary—in short, the *chemical action* of the liquid on the metal, though silent and quiet, is far more efficacious than our utmost labor can be. This chemical action is, in one sense, powerful friction, and, like friction, it produces electricity.

(Art. 155.) For the purpose of explaining the theory of Galvanic electricity, we present Fig. 116. It represents the cups *A* and *B*, each containing diluted nitric or sulphuric acid, and two pieces of metal in each cup, one of zinc, marked *Z*, and one of copper, marked *C*.

Fig. 116.



The copper of one cup must have a metalic communication with the zinc of the next cup.

To understand the manner in which Galvanic electricity may be developed, let us commence with the zinc plate in the cup *A*. The action of the acid on the zinc plate produces or induces, or excites electricity, which is *positive*, and as the liquid is a conductor of electricity, this positive electricity is conducted to the copper plate; thence along the plate, and along its metalic connection, to the zinc in the next cup *B*. The action of the acid in this cup *B*, on its zinc plate, also induces positive electricity, which is added

to that coming from the cup *A*, and together they pass through the liquid in this cup to the copper plate. Thus we might pass on from cup to cup, accumulating electricity all the way.

Let it be borne in mind that the action of the acid on the zinc plate produces *positive* electricity; but the electricity so excited is instantly carried away by conductors, and leaves the *pole* at the zinc side of the battery in a negative state,* and the pole at the copper side of the battery is in a positive state, *and the positive current flows through the conducting wire* from the copper to the zinc.

By the theory of two fluids, a negative current must flow in an opposite direction; but, to avoid confusion, we represent only one current. When we have but one cup, and a connecting wire between the copper and zinc, we call the apparatus a *simple Galvanic circle*, when more than one cup, we call it a *compound Galvanic circle*, or a Galvanic battery.

(Art. 156.) There are many forms for the Galvanic apparatus—but they are all on the same principle, as explained in Art. 155. Indeed there are no batteries now constructed with cups, as represented in the last cut, but that is the best form to explain the principle—the best practical forms cannot be clearly represented on paper. The cups require too much liquid, and they are in every way troublesome and cumbrous. For small experiments, for the purpose of experiencing the sensation of Galvanism, the simplest and least expensive apparatus is a set of 30 or 40 pair of zinc and copper plates, six inches long and three or four inches wide. With such plates we can form the *Galvanic pile*.† Commencing with a plate of copper, on it put a plate of zinc, and then a piece of cloth, wet with salt and water, or, what is better, acidulated water; and on this cloth put on copper, and then zinc, and so

* Some authors have explained the single pile as being positive; but we know by the action of the gold-leaf electrometer, that positive electricity flows from the copper pole of the battery.

† In other books, this is called the VOLTAIC PILE, from Alexander Volta, a pupil of Galvani, who first invented and experimented upon it. A modification of this pile is the Galvanic battery, often called the Voltaic battery. We also hear of Voltaic electricity, &c. Undoubtedly, Volta deserves as much credit as Galvani; but to avoid an unnecessary number of names, and a consequent confusion of ideas, (at least for a time,) we shall uniformly say—Galvanism, Galvanic battery, Galvanic electricity, &c.

continue through the whole series—*copper*, *zinc*, *cloth*; *copper*, *zinc*, *cloth*, &c.

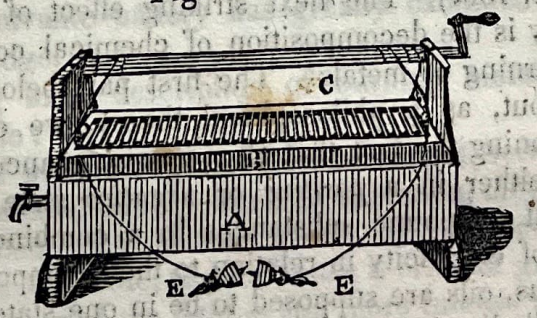
To experience the sensation, wet the hands and wrists *thoroughly*, and touch (as lightly as possible) with both hands the extremities of the pile, and as often as the contact is made, slight electrical shocks will be experienced. If a conducting wire is carried round from one extremity of the pile to the other, small sparks will be seen as often as the circle is closed and broken. (Connecting the extremities of any Galvanic apparatus, by means of any conductor, is called *closing the circle*.)

When the zinc plates become corroded and blackened by the action of the acid, the operation gradually ceases, and can only be resumed by increasing the acid, or cleaning the plates. The pile should be insulated.

(Art. 157.) The most convenient and efficient kind of a Galvanic battery was suggested by Dr. Wollaston. It is so arranged that each zinc plate is quite surrounded by a copper plate, and insulated from it. A battery of this kind is represented in Fig. 117.

A is a trough to contain the acidulated liquid, *B* is a case round the plates, and is connected by a cord or chain to a windlass, for the purpose of lowering or raising the plates out of the liquid, at pleasure. *EE* are small handvices, attached to the poles for the purpose of holding substances in, to be experimented upon.

Fig. 117.



The zinc plates are confined in copper cases, insulated by baked wood at each end, and to secure the zinc and copper from touching at the center of the plates, pasteboard, saturated with oil and wax is placed between them.

The proper connection between the zinc and copper at the extremities of each piece, is made by soldering strips of copper. The size and number of plates may be varied at pleasure.

The largest size battery ever constructed was that of Mr. Children, of England, the plates of which were 6 feet long, by 2 feet 8 inches wide.

A *great number* of plates will give powerful shocks; plates of *large size* will produce great heat.

The same surface of plate, when broken into many plates, will not produce as much heat as one or two pieces; but the shocks will be far greater. In one case, electricians say there is great *tension*—and in the other, in the case of great heat, they say there is great *quantity*.

(Art. 158.) We know that Galvanism, (so called,) is the same, in its essential nature, as common electricity, from the fact that the *Leyden jar* can be charged from either wire of an unbroken circuit, provided the battery has considerable *tension*, or is composed of a considerable number of plates, and is in vigorous action. Common electricity has great *tension*, and Galvinic electricity has great *quantity*—and *this is the principal difference between them.*

Galvanic electricity will pass a short distance through the air, or along non-conductors, creating sparks, and producing light and heat. Hence, like common electricity, it will inflame combustibles, such as phosphorus, alcohol, gunpowder, and the inflammable gases.

(Art. 159.) The next striking effect of the Galvanic battery is the decomposition of chemical compounds, and the burning of metals. The first part belongs to chemistry; but, as a philosophical theory, we cannot forbear mentioning the fact, that all *simple* substances are supposd to be either in a *positive* or *negatice* state of electricity, and all compound substances in a combined and *neutral* state of electricity in relation to their component parts.

Thus, oils are supposed to be in one state of electricity, and alkalies in another, because an oil and an alkali, when brought together, will closely unite and form a new substance (soap), and it is supposed they unite from the attraction of their opposite electricities.

So, oxygen is a gas in one state of electricity, and hydrogen is a gas in another state of electricity—and this is supposed to be the reason why they will unite and form water—and water then must be in a neutral state of electricity, in respect to these gases.

Oil and water will not unite, and from this fact we infer that in *this connection* they are in the same electrical state. Those different substances which have a tendency to unite are said to have a chemical *affinity* for each other; and those substances which have no such tendency, or a repulsive tendency, are said to have no chemical *affinity*.

Now if this theory is true, as a consequence, we should expect that when we bring one of these compounds to the action of a battery, the natural force of the electrics of the ingredients will be overcome by the greater electrical power of the battery—and facts exactly correspond to this hypothesis. Water, brought to the influence of the Galvanic battery, is immediately resolved, particle by particle, into its original elements, oxygen and hydrogen—the oxygen going to the *positive* pole of the battery, and the hydrogen to the *negative*. From this we infer that the natural electrical state of oxygen is *negative*, because it goes to the *positive* pole, and that there is more electricity at the pole of the battery than in the hydrogen with which the liberated oxygen was just connected. But we will not enlarge on this subject, as it belongs exclusively to chemical philosophy. We only add, that this decomposing power of the Galvanic battery has greatly extended our chemical knowledge.

The following brief description of burning metals is given by Dr. Gale:

"If a piece of gold or silver leaf be brought between the poles of a powerful battery when in operation, they are instantly consumed; the former giving off a splendid white light tinged with blue, and the latter a brilliant green of the emerald tint, and the light is still more intense than that from gold; copper burns with a bluish white light, throwing off red sparks; lead gives a vivid purple. Indeed, the most refractory metals are not only melted, but dissipated in vapor by means of this instrument."

We would remind the reader that this phenomena which we here call burning, is not strictly so, according to the

common acceptation of that term, for it will take place in a vaccuum, or under water.

(Art. 160.) The power of Galvanic batteries does not increase in the same arithmetical proportion as either the size or number of the plates; the *decomposing power* of a battery which depends on both *quantity* and *tension*, seems to correspond to the *square root* of the number of plates; thus, if we have two batteries, one consisting of 4 pieces of plates, and another of 400, the decomposing power of the one will be to that of the other as 2 to 20, or as 1 to 10.

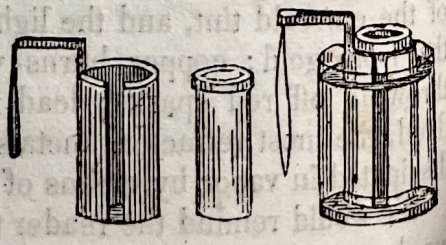
(Art. 161.) A more recent and convenient form of a simple battery is that of two copper cylinders, one within the other, soldered to the bottom, and the excited liquid put in between the two cylindrical surfaces. A cylinder of zinc is made to fit into this cylindrical space without touching either side or bottom of the copper vessel. The zinc cylinder is insulated from the copper at the top by ivory handles which rest on the rim of copper. The poles of the battery are little cups, to contain mercury on the extremity of a short thick wire, one of them is soldered to the copper vessel, the other to the zinc cylinder.

By thus exposing a large surface of zinc to a similar one of copper, Professor Hare, of Philadelphia, melted the most refractory metals, and created the most intense heat; and from this circumstance he called the instrument a *calorimeter*, meaning heat creator.

This kind of battery is now mostly used for common small experiments, and for common electro magnetic experiments, to be described in a future chapter.

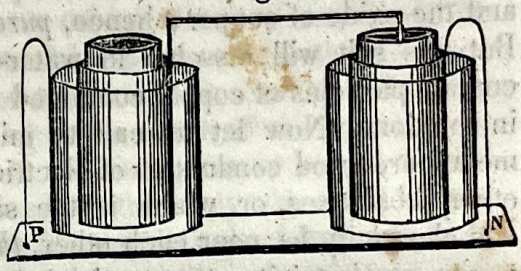
But this is the age of improvement, particularly in this branch of science; an improvement on this kind of Galvanic apparatus has been made by a Mr. Grove, called Grove's battery—it consists of glass cups or tumblers, to receive a circular sheet of zinc, having an arm or protuberance extending upwards, and turning horizontally, as represented in (Fig. 118;) a slip of platina is soldered to the end of the zinc arm, and hangs vertically.

Fig. 118.



A porous or unglazed earthen cup is made to fit loosely into the circular sheet of zinc, the rim of the earthen cup to rest on the top of the zinc. The parts put together, and we have the zinc in the glass cup, the earthen cup in the zinc. Several of these glass cups placed together, or nearly side by side, so as to have the slips of platina from one zinc to hang into the earthen of the next cup, and then we have the form of this battery, which is represented in (Fig. 119.) *P* and *N* are the poles.

Fig. 119.



For the exciting liquids, the glass cups are now filled with a weak dilution of sulphuric acid and water, say 1 of acid and 30 of water, and the porous cups are filled with strong nitric acid.

The electricity will pass through the pores of the earthen cups, but the liquids will not mix through them.

The Galvanic action depends on having two metals, one that will oxidize rapidly, and the other that will not—and zinc and platina are the very two metals in question. Zinc will oxidize more rapidly than any other metal, when acted upon by an acid, and platina is the most difficult of all to be acted upon; hence a stronger acid can be put into the earthen cups where the slips of platina fall.

A wire connecting the two poles *N* and *P* completes the circuit and sets the battery in motion (when the parts are put together and the proper liquids in the cups), and this wire may be the simple distance, a few inches or a few feet between the poles, or the wire may be long enough to pass round the room in which the battery is placed. The electricity, (in the language of theory,) will pass along the wire from pole to pole, *let the wire be longer or shorter*—and in fact the wire may pass round from New York to Cincinnati and back to unite the poles, as well as to pass round the room to unite them; it would only require a more powerful battery. Such long wires are actually used in the magnetic telegraph, an operation which we shall explain at large in a future chapter.

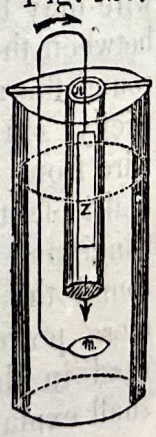
(Art. 162.) The strong decomposing power of galvanic electricity has enabled artists to bring it to their aid in gilding, silvering, and platinizing surfaces; also for making exact types of medals, coins or casts in metal, called *electrotype*, because a *type* is taken by means of *electricity*.

It is well known to all who have the least knowledge of chemical compounds, that many of the metals can and do exist in some of the salts, either natural or artificial.—Thus, the salt *blue vitriol*, which we can purchase at any apothecary shop, is a chemical compound of *sulphuric acid* and the oxide of copper; hence, *pure copper* is in the salt. But this salt will dissolve in water—then the liquid will contain particles of copper combined with other substances in solution. Now let us call to mind the fact, that the metals are good conductors of electricity, much better than other substances, or, which is the same thing, if a metal and electricity be near each other, *the metal attracts electricity, or electricity attracts the metal*, and of course, if a current of electricity or Galvanism can be made to circulate through any solution of a metalic salt, the electricity will find the particles of pure metal, and draw them away from any combination.

On this principle, particles of one metal may be drawn to, and attached, to the surface of another metal, or concentrated in a mass by themselves.

The Galvanic apparatus for this purpose is very simple. It consists merely of an earthen or glass cup, and a smaller porous cup made of thin leather, or a glass cylinder with a piece of bladder tied over the bottom; the smaller porous cup is made to go inside of the larger cup, and the two together are represented in Fig. 120. The porous cup is to be filled, or nearly filled, with a weak dilution of sulphuric acid and water, and then it is to be put into the larger cup containing a solution of metalic salt—let us suppose sulphate of copper. When thus arranged, a piece of zinc, to which a copper wire is attached, is put into the inner cup and the wire is bent round into the metalic solution. The action of the acid on the zinc excites electricity,

Fig. 120.



which passes through the porous cup, and by means of the wire and liquids, a complete Galvanic circle is formed—the positive pole at the lower end of the zinc, and the negative pole at the lower end of the wire, in the metalic solution; but metals are positive electrics, and always go to the negative pole; therefore, if any electricity is passing about this pole it will collect the pure copper from the solution; and such is found to be the fact.

If the copper wire is covered with wax, varnish, or any non-conducting substance, and thus connected with any any other metal, such as a medal or cast of any kind, the back and edge of the medal also covered with wax, then the copper will collect on the face of it, forming solid copper exactly corresponding to the shape of the medal, giving a reversed copy of it. If the figure is raised in the medal it will be depressed in the copy, the right of the original will be the left in the copy; indeed they will bear the same relation to each other as the printer's type and the printed sheet.

To keep the metalic solution saturated, a little of the salt or sulphate of copper is tied in a rag, and suspended in the liquid. In 24 or 36 hours, the copper will be sufficiently thick on the cast, and it can be taken off by the careful incision of a knife blade between the two metals, as the copper does not *positively cohere* to the other metal.

It is better that the time should be 36 than 24 hours, as the copper requires time to concentrate in small and solid particles. If the Galvanic action is vigorous, the copper will be collected rapidly, but coarsely and less perfectly; hence the acid acting on the zinc should be very weak, as weak as possible, consistent with precipitation.

We have thus far shown the principles that govern this art, and when that is understood the artist can modify the operation in a variety of ways, to suit his fancy, or render the effect more complete and perfect.

We have seen that if we take the metalic deposite directly on the medal, we have a *reverse* copy—that is, if the images and letters are raised on the medal they will be depressed on the copy, &c. To remedy this, a cast or model must be taken of the coin or medal, by means of

plaster, wax, or New'on's fusible metal. Moulds of plaster are made the same as stereotypers make moulds for type, and the mould thus formed is lightly touched over with boiled linseed oil, and this film of oil is covered over with fine pulverized black lead, to render its surface a conductor of electricity, that it may attract the metal from the solution. Great care must be taken that the indented parts are not too much filled with the lead, and the raised parts not too thinly coated.

The operator will next secure a metalic contact between the wire which comes from the zinc and the black lead.

Plaster moulds are made for taking copies of wood cuts, engraved stones, and other works of art, made on substances that will not bear a great degree of heat.

Wax moulds are made by running melted wax on the face of the medal we wish to copy, taking such precautions as will enable us to remove the mould from the medal without injury to either.*

The wax mould must be covered with black lead, the same as the plaster mould just described, and for the same reason.

Moulds of coins, and other small devices in metal, are best taken in the fusible metal, made by melting together 8 parts of bismuth, 5 of lead, and 3 of tin. This alloy melts at about the temperature of boiling water; hence, it may be used in a fused state without any danger of injuring any other metal.

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*Note. As this is a work of art, and not a principle of philosophy, we do not describe the *modus operandi*—and should we do so it could not be followed with success, without some practice. We might describe the whole operation of tanning leather, and making a boot, and the reader might well understand us, but, notwithstanding, he would require practice, to succeed in the art. So it is with this. The pupil, and even the teacher, can only learn general principles from books—and hence, some of our best teachers meet with indifferent success in making philosophical experiments; for the manipulations do, in fact, belong to the mechanical arts.

Melt a little of this alloy, and turn it out on a smooth, hard table—draw a piece of paper over it, to take off the dross, and then gently and silently press the coin or medal into it until it cools; next, melt off the superfluous metal at the edges, and melt in the conducting wire on the back; then cover the back, edge, and conducting wire with varnish or wax, to prevent a deposit of metal upon them.

Now all is ready for the action of the Galvanic current; the zinc being put into the central porous cup, and the mould on the conducting wire into the outer cup containing the metalic solution. Steadily and surely, particle by particle, will the metal from the solution come and rest on the mould—and if the mould is exact, the copy will be exact, for the action of the fluid can neither have fancy nor caprice, it copies every lineament, letter, and line, and, like the most mechanical Chinese, it follows the pattern in every blemish as regularly as in every perfection.

On the same general principle, there can be no difficulty in precipitating any metal from its solution, and causing it to adhere to other metals by a more energetic action of a battery—and this is called silvering, gilding, &c., according to the solution of the metal used.

But to do this *economically and successfully*, requires a short practical apprenticeship, and particular attention in reference to the chemical solutions of the metals.

(Art. 163.) There are several simple facts of some importance, that may be explained on the principle of Galvanism. For instance, a clean knife blade, simply dipped into a solution of the sulphate of copper, the knife blade becomes plated with copper. On the same principle, clean silver, coming in contact with sulphureted hydrogen, the silver is blacked by the sulphuret of silver.

No *two* metals should be used for any purpose, in any exposed situation, where one will do as well; for there will be a Galvanic action between them which will more rapidly corrode the one most susceptible of corrosion. Some years ago this was not well understood, and the copper on the bottom of ships was fastened on by iron nails; but by the action of the salt water on the two metals, copper and iron, the nails corroded away in an astounding short period of time, and iron fastenings were finally abandoned; and

now when we see a ship advertised for sale, the advertisement is very particular to state, that the ship is coppered and *copper fastened*. The reason why it should be so, is now apparent.

CHAP. VI.—MAGNETISM—THE MAGNETIC NEEDLE, ITS POLES, ITS GENERAL POSITION NORTH AND SOUTH, ITS DIP—MAGNETISM COMMUNICATED BY INDUCTION—THE EARTH A MAGNET—HOW SHOWN—MAGNETISM AND ELECTRICITY COMPARED.

(Art. 164.) It has long been known that a certain ore of iron, (the lowest oxide,) called loadstone, possessed a very mysterious and singular quality of attracting iron and steel. It was subsequently found that the same power could be communicated to steel by rubbing it on the first mentioned ore, and still later, other means have been found to communicate the same influence, as we are about to explain.

After bars of steel have acquired this power, they are called *artificial magnets*, to distinguish them from the natural *loadstone*.

Small magnets, balanced horizontally on a center, and free to turn in a horizontal direction, will always rest in a position nearly north and south. A circular horizontal plate, divided off into 32 equal divisions, and 360 degrees, together with a magnet, is called a *compass*—the magnet part is commonly called the needle, or *the magnetic needle*.

The invention and history of the compass is lost in the darkness and confusion of former ages; but we think it is claimed by both the Egyptians and Chinese. But, by whoever discovered, the simple fact, that the magnetic needle would, at all times, and in all places, rest nearly north and south, has tended more to the benefit of mankind than any other discovery in art or science, for without it none would dare to traverse the ocean—and, in short, this solitary fact, this mysterious property of a *single substance*, seemed to be a special blessing sent from God to man.

In early times, when investigations and observations were less accurate and definite, it was taken for granted that the needle pointed *exactly* north and south; and it is said that even Columbus, in his first voyage of discovery, was unacquainted with its variation, and when he sailed out into the Atlantic, where the deviation was so considerable as to force attention, he began to lose confidence in it as a guide, and in consequence, his crews became alarmed, and this was one cause of a threatened mutiny.

The force of magnetism has now become a science. It has been studied mostly for the purpose of understanding the needle; but not a particle of light was brought upon the essential nature of this power which governed the needle, until the year 1819, when Professor Oersted, of Copenhagen, showed it to be a state or modification of electricity.

(Art. 165.) *Electricity has two states, positive and negative—magnetism has two poles, north and south.*

If we bring two magnetic needles near together, we shall find that their north ends mutually repel each other—their south ends will repel; but the north end of one will have a strong attraction for the south end of the other, and thus we establish the fact, that *like poles repel, and unlike poles attract each other.*

To show that magnetism accumulates at or near the ends of a magnet, place a magnetic bar under a piece of paper, and on the paper sprinkle dry iron filings—they will arrange themselves around two points near the extremities of the magnet, clearly pointing out two poles.

The middle of a magnet seems to have no magnetic influence, and in this respect a magnetic bar is similar to an insulated conductor of electricity, as explained in Art 144; the middle of the conductor is neutral in its influence and power.

We never can have north polarity or south polarity alone. If a magnet be broken in the middle it will not separate the poles, for each piece will be a separate magnet, and have a north and a south pole.

A moderately long magnet (other circumstances being equal) is more powerful than a short one, and the nearer the two poles are the more powerful it is; therefore, to

bring the poles near together, the bar is bent in the shape of a horse shoe, and this is called the *horse shoe magnet.*

The strength of a magnet is not in proportion to its size. Very small magnets have been known to lift 200 times their own weight, while large ones will not lift more than 15 or 20 times their own weight, and very large ones may not lift so much; their proportional power corresponds more to their *surface* than to their weight.

The power of a magnet is increased by use; thus, let a piece of steel be suspended by a magnet, and attach as much weight to it as it will bear—and it will be found that it will sustain more and more weight each day, to a certain limit.

"Great weights have been supported by permanent magnets for a long series of years. The suspension of Mahomet's coffin, in his shrine at Mecca, is an instance," and his immediate followers caused the people to believe that this was a perpetual *miracle.*

The magnetic force varies *in the inverse ratio of the square* of the distance; that is, if we take any distance from the magnet and measure its force of attraction, at a double distance the attraction will be one-fourth as great, &c.; the same law that governs the intensity of light and electricity.

(Art. 166.) The magnetic influence may be communicated to steel bars by induction, by contact, and by the friction of another magnet, applied in a peculiar manner.

An iron key, or any other piece of iron or steel, may be held up by the power of a magnet, and this key or piece of steel will sustain another small piece, tbe same as if it were an original magnet, and it receives its magnetic power by *induction.*

A needle may be magnetized by drawing one pole of a magnet from the center of the needle to one end several times, and then draw the other pole of the magnet from the center to the other end several times. The north pole of the magnet will give south polarity to the needle, and the south pole of the magnet will create or induce the north pole on the needle.

The earth itself is a great magnet, and it will induce magnetism in iron and steel, on the principle of induction.

A bar of iron standing in, or near a perpendicular position (in this latitude) will gradually acquire magnetic power. The iron bars that support the gates in the locks of the Erie Canal, have become highly magnetic; and on this principle, old tongs, pokers, and fire shovels become, in time, more or less magnetic.

To show that iron is thus magnetized by the earth, and not by heat, cold, or the action of water, &c., take a bar of *soft iron*, place it as near as possible north and south, with the north end on the ground, and the south end at an altitude of 40 or 50 degrees; then bring a delicately suspended needle near the north end of the iron; the north pole of the needle will be *repelled*, and the south pole will be attracted, showing that the bar has north polarity. Now reverse the position of the bar, and put the other end to the ground, and the magnetism of the bar is instantly reversed, showing that the whole action is due to the power of the earth. Of course, the north pole of the earth has the same kind of polarity as the south pole of the bar of iron, or the south pole of the magnetic needle. In this experiment we must use a bar of *soft iron*, because a bar of steel becomes *permanently magnetic*, when magnetized at all—it cannot instantly reverse its poles by induction from another body.

It will also be observed that the position we have directed was neither horizontal nor perpendicular, but it was in a direction towards one (the north pole) of the poles of this great magnet the earth, and when a magnetic needle is freely suspended *in all directions* it not only points north and south, but also *dips*, and takes a direction towards this pole, which is in a north direction, and beneath the surface of the earth.

Hence, the magnetic needle has *dip*.

In latitude 40 degrees north, on the American continent, the dip is about 48 degrees from horizontal. At London, in latitude 51 degrees, it is 72 degrees, and the direction of the compass and the position of the dip, as observed from various places, point out the north magnetic pole to be in latitude about 82 degrees, and longitude about 75 or 80 degrees west of Greenwich, and situated between two and three hundred miles under ground. At this point,

then, on the surface of the earth, wherever it is, a needle balanced horizontally will rest indifferently in all directions, and the dip will be perpendicular. The southern pole is not so clearly defined; but it is probable it cannot be far from the opposite position in the earth. In the Atlantic ocean the variation is west; that is, the needle points west of north, from 1 to 24 degrees, according to locality; through western New York and western Pennsylvania, it is nearly due north; west of this the variation is east, and in the Pacific ocean, west of America, it is about 20 degrees east. In short, the general direction of the needle all over the northern hemisphere runs to the point we have designated as the magnetic pole.

The variation, however, is not uniformly the same in the same place—it is changeable by slow progressions. At London, in the year 1580, the variation was 11 degrees east; in 1805, it was 24 degrees west, and it is now nearly stationary, or slowly declining again towards the east.

The cause of these variations is not known. We cannot conceive why the earth should be a magnet at all, unless a great portion of its material substance is composed of iron, and then its poles may change, in consequence of internal changes in the body of the earth.

The astronomer and the navigator can at any time determine the true position of the sun on observing its altitude, and if their compass shows the same position at the same time, then the compass has no variation; but if the sun is in any other direction by the compass, then that compass has a variation just equal to the difference between the known direction of the sun, and its direction per compass. The entire operation of finding the variation at sea, is called taking an Azmuth.

The mean variation is not the same at all times of the year, nor at all hours of the day. In the western hemisphere, the greatest variation is in summer, the warmest season of the year, and the greatest variation for a day is at the warmest time of the day, between two and three o'clock in the afternoon; and hence, we have an annual and a diurnal variation—both very small, and unnoticed and unknown by the common observer, but are clearly distinguishable by delicate experiments, and are evidently con-

nected with the heat and cold of the earth. The greatest daily variation is about one-fourth of a degree, and the greatest annual variation a little less. The north magnetic pole is supposed to be at, or near, the point of greatest cold.

The line of no-variation is very irregular and variable, extending quite round the globe; at present it runs across Lake Erie, near the town of Erie, in Pennsylvania, thence southward, and passes into the Atlantic near Cape Henry, and runs through the western portion of South America; its position in the eastern hemisphere is not so well defined, and is more irregular.

There is a line east and west round the earth where there is no dip, and this line is called the *magnetic equator*. It is a very irregular curve, and cuts the geographical equator in two points, and never departs more than 6 or 8 degrees from it; and in the western hemisphere it is in south latitude, and in the eastern hemisphere in north latitude.

(Art. 167.) We conclude this chapter by observing, that magnetism must have some connection with electricity—for in some particulars they are much alike, in others *totally unlike*.

Magnetism is weakened by heat, and destroyed by a white heat. A stroke of electricity will destroy the power of a magnet, or reverse its poles.

Magnetism is supposed to be *light*, *heat* and *electricity* combined, and the only substance in which they will combine is iron and steel.

Magnetism, like electricity, has two states, or two poles, which have mutual attraction and self-repulsion.

Both magnetism and electricity can be communicated by induction.

In the following particulars, they are totally unlike—Electricity can be produced on every insulated substance; magnetism on only two, iron and nickel, in the latter very feebly.

Electricity is always transient—magnetism on soft iron is transient, but on carbonised iron it is permanent.

Electricity has many conductors—magnetism has but one, iron, or the compounds of iron.

Electricity is lost or carried away by action—magnetism is increased by action.

Electricity can be insulated, and cannot show its action through glass and many other substances; on the contrary, the magnetic influence is not even weakened by the intervention of glass or any other substance, *iron*, *steel* and *nickel* excepted, and the influence also is the same through liquids, and in a vaccuum.

CHAP. VII.—INFLUENCE OF AN ELECTRICAL CURRENT ON A MAGNETIC NEEDLE—SOFT IRON MAGNETISED BY THE ELECTRIC OR GALVANIC CURRENT PASSING ROUND IT—THE MAGIC RING—THE MAGNETIC TELEGRAPH—A TELEGRAPHIC LETTER THE EARTH A MAGNET—HOW SHOWN—THE SUPPOSED INFLUENCE OF ELECTRICITY ON CLIMATES—THE TELEGRAPH RESUMED—RELAY MAGNETS AND STATION BATTERIES EXPLAINED.

(Art. 168.) It was observed in an early day, that the poles of a magnet could be reversed by electricity, and that a lightning stroke could communicate magnetism to pieces of iron which did not previously possess it. These facts suggested the possibility of making artificial magnets by means of galvanism and electricity; but no results of importance were attained until 1819, when Professor Orested made the important discovery that a current of galvanic electricity (so called) had a tendency to *settle the magnetic needle at right angles to the current.*

On placing the wire, which closes the circuit of a galvanic apparatus, *above a magnetic needle and parallel to it*, the needle has a tendency to move in the horizontal plane either east or west, according to the direction of the current from the battery.

When the wire is placed in the same horizontal plane with the needle, the needle shows no inclination to move either east or west—the tendency is then to move up or down in the vertical plane. When the wire is on the west side of the needle, and in the same horizontal plane with

it, and the galvanic current supposed to move from north to south, the north pole of the needle will be elevated, and when the poles of the battery are changed, the south pole of the needle will be elevated. These experiments, and their results, give the entire fundamental principle of *electro magnetism.*

It is rare that the deflection is more than 45 degrees from the influence of a galvanic wire, owing to the magnetism of the earth; but the effects of the earth's magnetism can be taken away by another magnet of equal power brought near it, with its *poles* reversed; that is, the south pole of one magnet brought near the north pole of the other. The magnet *above* will then counteract the magnet *below,* (the earth,) and the *middle* magnet or lower needle will then fully obey the current of the conducting wire, and turn at *right angles.*

(Art. 169.) From these experiments, and the reflections and theories which they naturally induced in the minds of philosophers, it was finally discovered, *that a current of galvanic electricity* (so called) *circulating round iron would cause it to become magnetic.* Conversely, then: Ampere, a French philosopher, supposed that the natural loadstone, and artificial magnets also, held magnetic properties in consequence of galvanic currents circulating around them, and this hypothesis will account for all the facts mentioned in Art. 168.

To correspond with the facts as mentioned in Art. 168, Ampere supposes that the direction of the currents round a natural magnet must be as follows:—*Eastward on the upper side of the magnet, downward on the east side, westward on its under side, and upward on the west side.**

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* Note.—We state this on authority; but we incline to the opinion that these currents, if currents they are, flow in precisely the opposite direction, and the currents on the conducting wire repel those on the magnet; on this hypothesis we can more readily account for the facts observed, for opposing currents must have more efficiency in deflecting the needle than currents uniting to flow in one and the same direction.

Now we will suppose that the positive current of electricity passes along the wire, from the northward, as represented in Fig. 121, and directly over the needle *NS*. It is obvious, then, that if the north end of the needle turns to the eastward,* the natural currents on the needle and the currents along the wire will coincide and flow in the same direction.—When the wire is under the needle the north end must turn westward, to make the circuit along the wire correspond in direction to the currents under the needle. When the wire is in the same horizontal plane with the needle and east of the needle, the north end will be depressed; but the wire on the west side of the needle and its pole will be elevated. If we reverse the poles of the galvanic battery, and send the current along the connecting wire in the opposite direction, the needle will take the opposite positions, and in all cases correspond to these supposed currents around the magnet.

Fig. 121

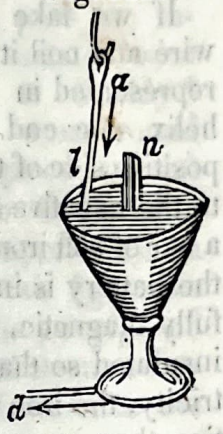
A single current passing over or under the needle along the conducting wire will not have sufficient energy to turn the needle at right angles, it will only have a tendency to do so; but we can increase the energy by insulating the conducting wire—that is, wrapping it, or winding it with silk and covering it with varnish, and then passing it round and round the needle many times, as represented by Fig. 122. The current of the wire will be in opposite directions, on opposite sides of the magnet, and its energy will act over and over again, according to the number of times the wire returns on itself. Such a coil will throw the needle at right angles.

Fig. 122.

* Note. The currents are represented in the opposite direction from that expressed or intended, and the representation now corresponds with the idea expressed in the note on the preceding page.

(Art. 170.) If a current of electricity does in fact circulate round a magnet, said Professor Faraday, it can be proved by experiment; and accordingly he devised the experiment as represented in Fig. 123.

Fig. 123.



A magnet *n* passes through the bottom of a cup; the cup is nearly filled with mercury, which is fluid, and a good conductor of electricity, and if electricity does circulate round the magnet the mercury will spread and enlarge such circles.—Now let a fine conducting wire pass down into this mercury, and a conducting wire pass to the magnet at the bottom of the cup from the other pole of the battery; we have then a perfect metalic circuit, and when the battery is in action (if it have considerable power) the wire will circulate round the magnet, clearly showing a current, or at least an influence which we may call a current.

As action and reaction are always equal, if we secure the wire in the center of the cup and give the magnet freedom of motion in the mercury, it must revolve round the wire; and this fact has often been confirmed by experiment.

Ampere invented a little galvanic apparatus to revolve on either pole of a horse-shoe magnet. It consists of two copper cylinders, one within the other, and a bottom made between them, forming a double cylindrical cup, or the space between the two cylinders forms the cup to contain the diluted acid.

A wire coil passes from the opposite sides of this inner cylinder, (which is about one inch in diameter,) and a point projects downwards from the upper part of the coil, this point is to rest on the pole or end of the magnet, and is the center of motion for the cup.

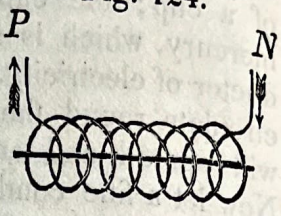
A cylindrical piece of zinc, with a similar coil and projecting point, is to be placed on the other coil, and the zinc let down into the diluted acid—then comes a galvanic action, and if the magnet is a strong one, the copper cup and the cylindrical zinc will both revolve round the magnet, the one in one direction, and the other in the other.

(Art. 171.) If it is true that currents of electricity passing round and round a piece of iron or steel, makes it

magnetic, we would at once infer that if an artificial electrical or galvanic current be made to pass round a piece of iron or steel it would create magnetic properties—and on trying the experiment the hypothesis is fully confirmed.

If we take an insulated copper wire and coil it round and round, as represented in Fig. 124, forming a helix, one end *P* passing from the positive side of the battery, and going to the negative side *N*. On putting a bar of soft iron into this helix when the battery is in action, the iron instantly becomes powerfully magnetic, and if the coils are many, and the wire insulated so that there is no lateral communication of electricity, the iron will have much stronger magnetic properties than any natural magnet of the same size; but the instant the iron is taken out of the helix, or the current of electricity stopped by breaking the circuit, the magnetic properties instantly vanish, and the iron is no longer a magnet. When the wires are changed in the poles of the battery, the polarity of the magnet is instantly changed.

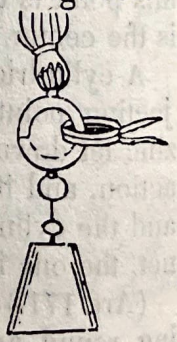
Fig. 124.



If we put a steel bar into the helix in place of soft iron, the magnetic properties are communicated more slowly and less energetically—but when once acquired they are permanent, and continue after the steel is taken from the helix. In this way magnetic needles can be thoroughly magnetized.

(Art. 172.) The most simple experiment to show the magnetic induction from a circle of electricity, is the *magic ring*, which consists of a coil of insulated copper wire as represented by Fig. 125, connecting the two poles of a battery. Now let there be two semicircular pieces of soft iron fitted together, or any two pieces of soft iron fitted as armatures, and let them be brought in contact one end of each in the ring, and they will *adhere very strongly*, and support 50 or 100 times their own weight, but in detaching one of the ends of the wire from the pole of the battery, the *adhesive power instantly ceases.*

Fig. 125.



(Art. 173.) This force, which sustains the weight as shown in the last article—this magnetizing power of an insulated copper wire—is made of great practical utility, in the far-famed *magnetic telegraph.*

Fig. 126.

For this purpose the insulated wire is thickly * wound round and round a piece of soft iron bent in the shape of a horse shoe, as represented in Fig. 126. By this figure we design to show the principle of making a powerful electro-magnet, and its application to the magnetic telegraph.

The strongest magnets are made by having several different coils of wire, and their like ends connected together so that several branches may apparently run from one wire as it comes from one pole of the battery, and the same wires all uniting and forming one wire before it reaches the other pole.

The most powerful magnet of this kind was made about 15 years ago, by Professor Henry, of Princeton College, New Jersey. The iron was about two inches in diameter, and five feet long, bent in a horse-shoe form, and wound with several thousand yards of insulated copper wire, and it supported a weight of 3500 pounds.

We believe Professor Henry applied the weight directly; but it can be applied on the principle of steelyards, as represented in the cut:—*M* is the magnet, *a* the armature, and when that adheres to the magnet in consequence of the action of the battery, we can slide a known weight on the bar, and according to the distance from the fulcrum when it raises the armature, we can compute the sustaining power of the magnet.

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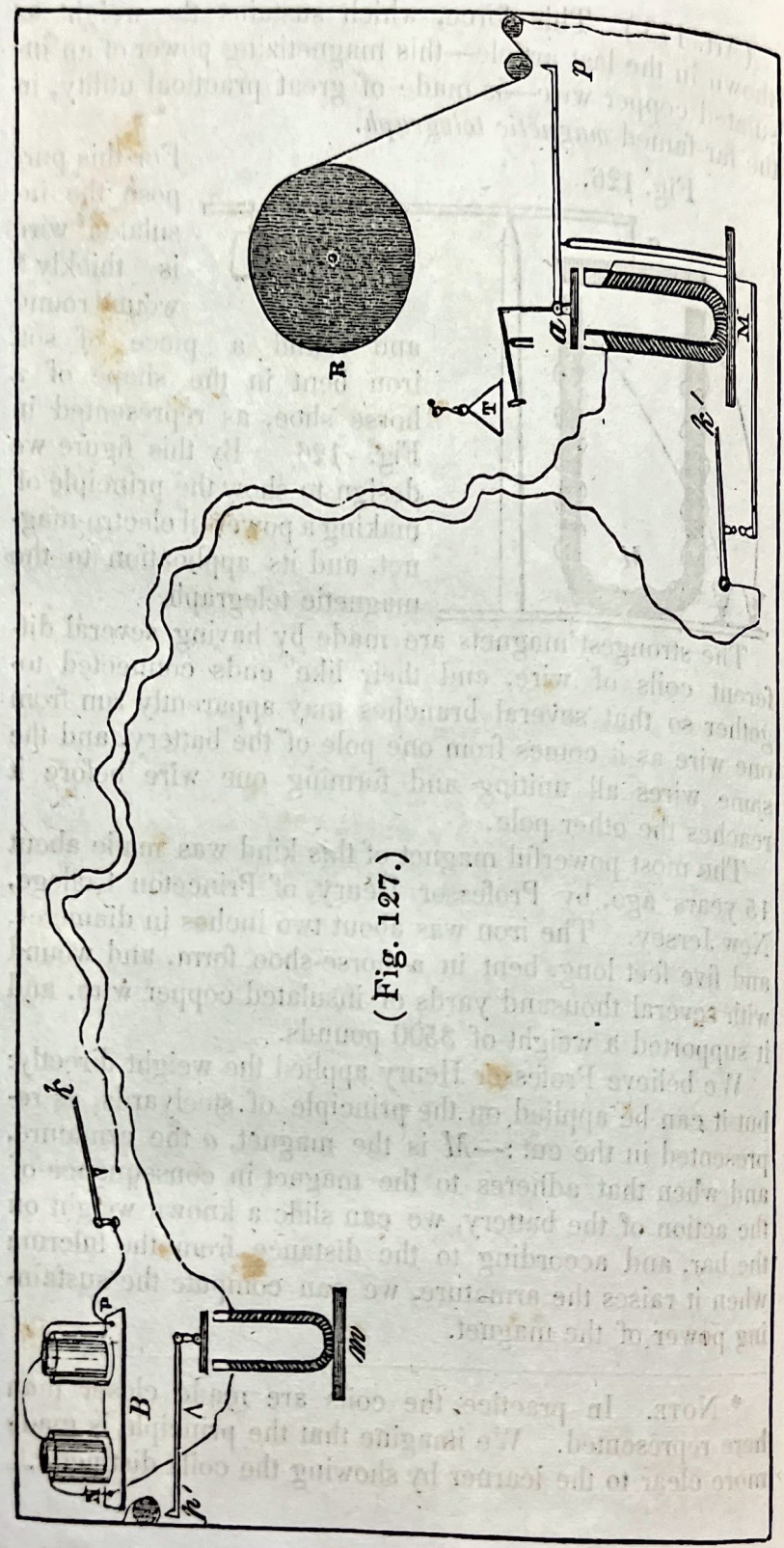
* Note. In practice, the coils are made closer than here represented. We imagine that the principle is made more clear to the learner by showing the coils distinctly.



(Fig. 127.)

The only difference there is between having the battery and the magnet in the same room, and having them 100 or 200 miles asunder, is, that in the first case the magnet is made a very powerful one, capable of supporting a great weight, and in the second case the magnet is more and more feeble, in proportion to its distance from the battery; but it is still sufficiently powerful to draw down a light and delicately balanced armature, and thus move a bar.

To understand the principle of magnetic telegraphs, let *B*, (Fig. 127,) represent the battery, *P* and *N* the positive and negative poles.

By inspecting the figure, it will be seen that the circuit of the battery is not quite closed, the lever springs *k* and *k'* separate two points at the extremites of the circuit. The points so separated are called the *hammer* and *anvil*.

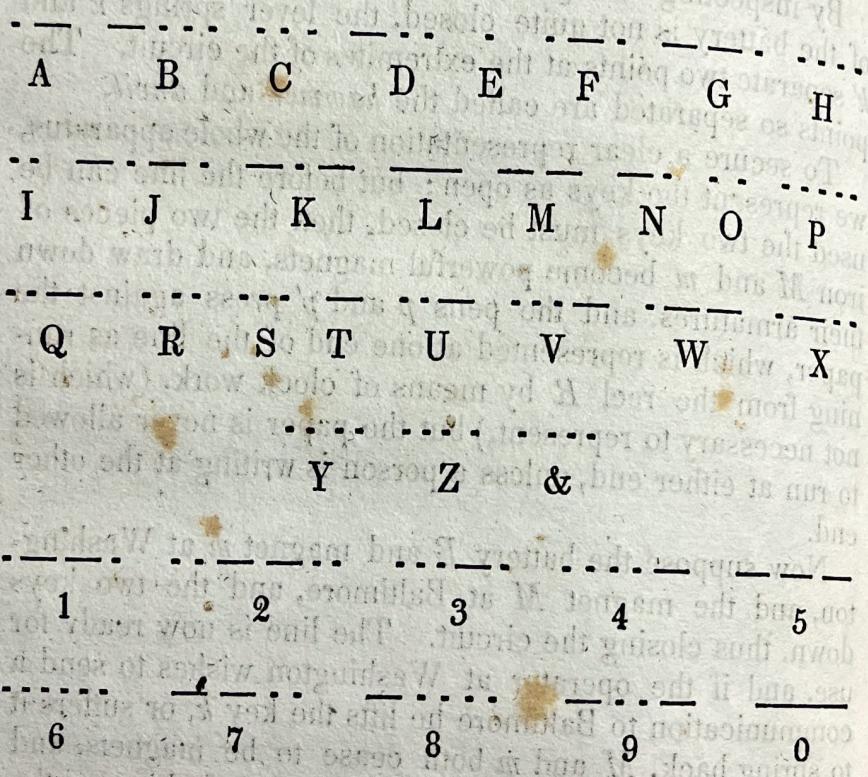
To secure a clear representation of the whole apparatus, we represent the keys as open; but before the line can be used the two keys must be closed, then the two pieces of iron *M* and *m* become powerful magnets, and draw down their armatures, and the pens *p* and *p'* press against the paper, which is represented at one end of the line as running from the reel *R* by means of clock work, (which is not necessary to represent,) but the paper is never allowed to run at either end, unless a person is writing at the other end.

Now suppose the battery *B* and magnet *m* at Washington, and the magnet *M* at Baltimore, and the two keys down, thus closing the circuit. The line is now ready for use, and if the operator at Washington wishes to send a communication to Baltimore he lifts the key *k*, or suffers it to spring back, *M* and *m* both cease to be magnets, and their armatures fly up, and to be certain of alarming the receiver at Baltimore, the triangle *T* may be made to ring as the armature flies up; but this contrivance is now generally dispensed with, as unnecessary.

As soon as this signal is made, the operator at the magnet *M* puts the weight on to his clock-work, and lets his paper run; the keys are closed, and he strikes his key *k'*, making his accustomed signals that all is ready, then closes his key, and the operator at Washington sends his communication. Sending a communication or despatch is

nothing more than operating on the key—closing and breaking the circuit at pleasure; and the operator has very much the appearance of playing on a *piano* which contains but a single key. A momentary pressure on the key makes a *dot* on the paper at the other end of the line, (or at both ends, if both operators have their paper running); a prolonged pressure makes a *dash;* a still longer pressure makes a *line;* and a combination of *dots*, *dashes* and *lines* form the following

TELEGRAPHIC ALPHABET.

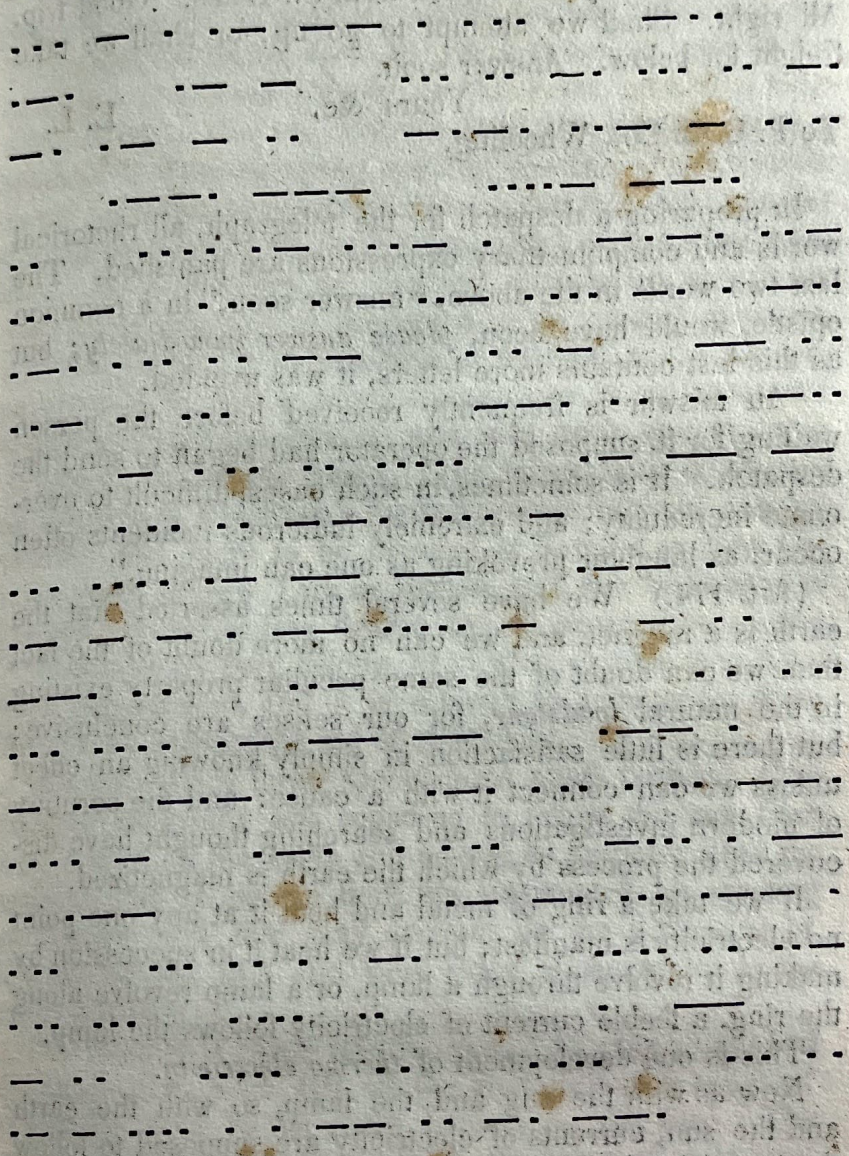


"It requires a very exact idea of time to separate the letters and words in that proper proportion which is necessary to successful telegraphic writing. And hence, comparatively few succeed in making their characters and words sufficiently distinct to render the sentiment at once intelligible in all cases.

"There are four kinds of spacing. 1st. That which separates the *parts* of a *letter* in proportion. 2d. That which separates *letters*. 3d. That which separates *words*. 4th. That which separates *sentences*. The first should be

less marked than the second, the second than the third, and the third less marked than the fourth—this of course being more extended than either of the others."

As a specimen of telegraphic writing, we give the following:



This despatch, properly construed, is the following. It purports to have been a communication from a steamboat captain to his employers, in a time of low water on the river; and on this account he was at a loss wnether to continue up the river or not. Without the aid of the

telegraph, he would have been compelled to act entirely on his own decision, as it would have required six days to communicate by mail. By telegraph it was done in ten minutes.

Steamer D. F. at Cincinnati, July 15, '47.

I have just returned from St. Louis. Good trip. All right. Shall we attempt to go up; or shall we take freight for below. Answer soon.

Yours, &c. E. L.

To P. O. & Co., Wheeling.

In preparing a despatch for the telegraph, all rhetorical words and complimentary expressions are banished. The last two words in the above, "answer soon," in a common epistle, would have been, *please answer immediately;* but as this last contains more letters, it was avoided.

"An answer is frequently received before the person waiting for it, supposed the operator had began to send the despatch. It is sometimes, in such cases, difficult to overcome incredulity; and extremely ludicrous incidents often occur, as laughter provoking as one can imagine."

(Art. 174.) We have several times asserted that the earth is a magnet, and we can no more doubt of the fact than we can doubt of the same peculiar property existing in the natural *loadstone*, for our senses are conclusive; but there is little satisfaction in simply knowing an effect unless we can connect it with a cause; and the scrutiny of modern investigations and searching thought have discovered the process by which the earth is magnetized.

If we take a ring of metal and heat it at any one point no electricity is manifest; but if we heat it in succession by making it revolve through a lamp, or a lamp revolve along the ring, a feeble current of electricity follows the lamp.

This is one development of *thermo electricity*.

Now as with the ring and the lamp, so with the earth and the sun, currents of electricity are supposed to follow the sun around the rings of the earth from east to west, and currents of electricity round iron, or any body containing any material portion of iron, gives the body magnetic properties, and thus the earth is supposed to be magnetized by the action of the sun heating it in succession

from east to west; and if the earth contains great quantities of iron, as it is reasonable to suppose it does, it must in consequence possess magnetic properties, and be in fact a magnet.

As a magnet has two poles, and the mid space between them is neutral, so with the earth, the two poles are near the equatorial poles, and the north magnetic pole of the earth has the same polarity as the south pole of a magnetic needle, and the regions near the equator have a neutral or less energetic state of electricity than either more northern or southern climes, and this may account for peculiarities of climate, independent of mere temperature. In a northern or southern climate we may have very warm weather, as measured by the rise of mercury, and yet producing no lassitude or delibility to the inhabitants, while in fact a lower temperature in an equatorial region will produce debility, and take away almost every energy of the human frame. The temperature of 90 and 95 degrees of Farenheit's thermometer is far more uncomfortable and more to be dreaded at Natchez or New Orleans than at New York or Boston, and this difference is felt in a greater or less degree by all persons, no matter to what country they belong, or to what climate they have been accustomed; and it is difficult to account for these differences without the aid of electricity.

We may carry these speculations much farther. Currents of electricity are supposed to follow the sun from east to west on the earth and among its particles near the surface, and of course they are interrupted on meeting mountains, and this may account for the difference of climate on the east and west sides of mountains in the same latitude.

The climate is much warmer, and, if we may be allowed the expression, more *soft* on the west side of a range of mountains than in the same latitude on the east. The word *soft* does not mean warm, in the sense of mere temperature, it means a feeling that no other word can as well describe, and none can fully understand who are wanting experience on the different sensations of climate. A person is more physically strong, more energetic on the eastern side than on the western, but, generally speaking,

he is not so comfortable—there is a savage harshness in the cold air on the eastern inclinations of a country which is never experienced on the western.

The climate on the eastern side of the Alleghany mountains in Pennsylvania, is comparatively cold for the latitude, the top of the mountain range very cold, but rapidly grows warmer on descending on the west side, and continues to grow warmer as long as the general slope of the country is westward. On passing the Mississippi river, or even before, the climate becomes colder and colder, and extreme cold is reached on the Rocky Mountains; but on the west side of these mountains the climate is warmer than on the west side of the Alleghanies—and so continues to the Pacific ocean; from here to China is a long extent of ocean, and the cold gradually increases so that it is colder on the coast of China than in the same latitude on the American coast—and these general observations will correspond with the peculiarities of climate in relation to latitude, and the localities of mountains, the world over.

If electricity does have any material influence on climate, the internal structure of the earth near any particular locality must also have its effect, for near large stratas of iron ore the earth must be more intensely magnetic than other localities where this metal is absent.

Currents of electricity on the earth and under its surface may and probably do induce others in the higher regions of the atmosphere, running in an opposite direction.

The currents of electricity run on the earth from east to west, following the general course of the sun, and this would give a general western direction to the higher aerial currents—and corresponding to these views, we find that all thunder showers, as a general thing, move from west to east, and, other circumstances being equal, they are far more frequent and more violent in a mountainous and mineral country than elsewhere.

(Art. 175.) The last article is apparently a digression; but as we are soon to use the earth as a magnetic wire, we wished the reader to be fully apprised that the earth was a magnet, and what caused it to be so. The wire connecting the poles of a galvanic battery not only communicates

magnetism to iron and steel, but is in itself magnetic, as is shown by its opposite sides having opposite polarities. The poles are not at the extremities of the wire, one at one end and the other at the other; but there seems to be a succession of short magnets equal to the diameter of the wire, for one side attracts one pole of a needle, and the other repels it. Now we may suppose an iron wire insulated on poles, and extending through the air for 20 or 100 miles, and the two ends extending into the ground, and if electrical currents do extend along the ground, and this wire being a good conductor of electricity, a better conductor than the ground itself, whatever current would pass along the ground will now pass along the wire, and thus the wire will always be in a high state of electrical excitement without any aid from an artificial battery, and of course artificial electricity, when applied, must instantly become sensible along the whole line.

We have thus far considered an actual current running along the conducting wire, and it may be so, but it is *extremely doubtful;* however, as we are really ignorant of the essential element in question, and in comparison to it our perceptions are gross, and our language wanting point and force to pourtray the distinct shades of thought, it may be best still to use the same terms of expression; but we are inclined to the opinion *that no real current and no actual substance passes;* but it is the undulation of a substance already there existing, that the electricity is already on the wire, and already in the ground, and any conductor is only *a passage to guide the undulation.*

When the magnetic telegraph was first put in operation, and for some time after, it was supposed that a complete circuit of wire was indispensable; but on several occasions the connecting wire broke, and its two ends fell to the ground, without interrupting its communications; and these circumstances led to the discovery that one wire connected at both ends with the ground was sufficient. In this position the conducting wires of a battery very much resemble the conducting wires of a common electrical machine, the wire from the ground to the rubber corresponds with the wire from the ground to one pole of the battery, and the wire from the prime conductor to the

ground corresponds with the long wire from the battery which finally terminates in the ground, and it is said that the machine takes electricity from the ground and carries it to the ground; so the electricity excited by the galvanic battery takes the electricity from the ground and carries it to the ground; and if this view be taken, there is no necessity for supposing a *return of a fluid through the ground*—a supposition that does some violence to our hitherto sober imaginations.

(Art. 176.) In Art. 173 we have explained the general principle of a magnetic telegraph—and we now continue, on the supposition that so far it is understood by the reader. We there explained the operation of only a short line, with only two stations, one at each end of the line, both operators using one battery.

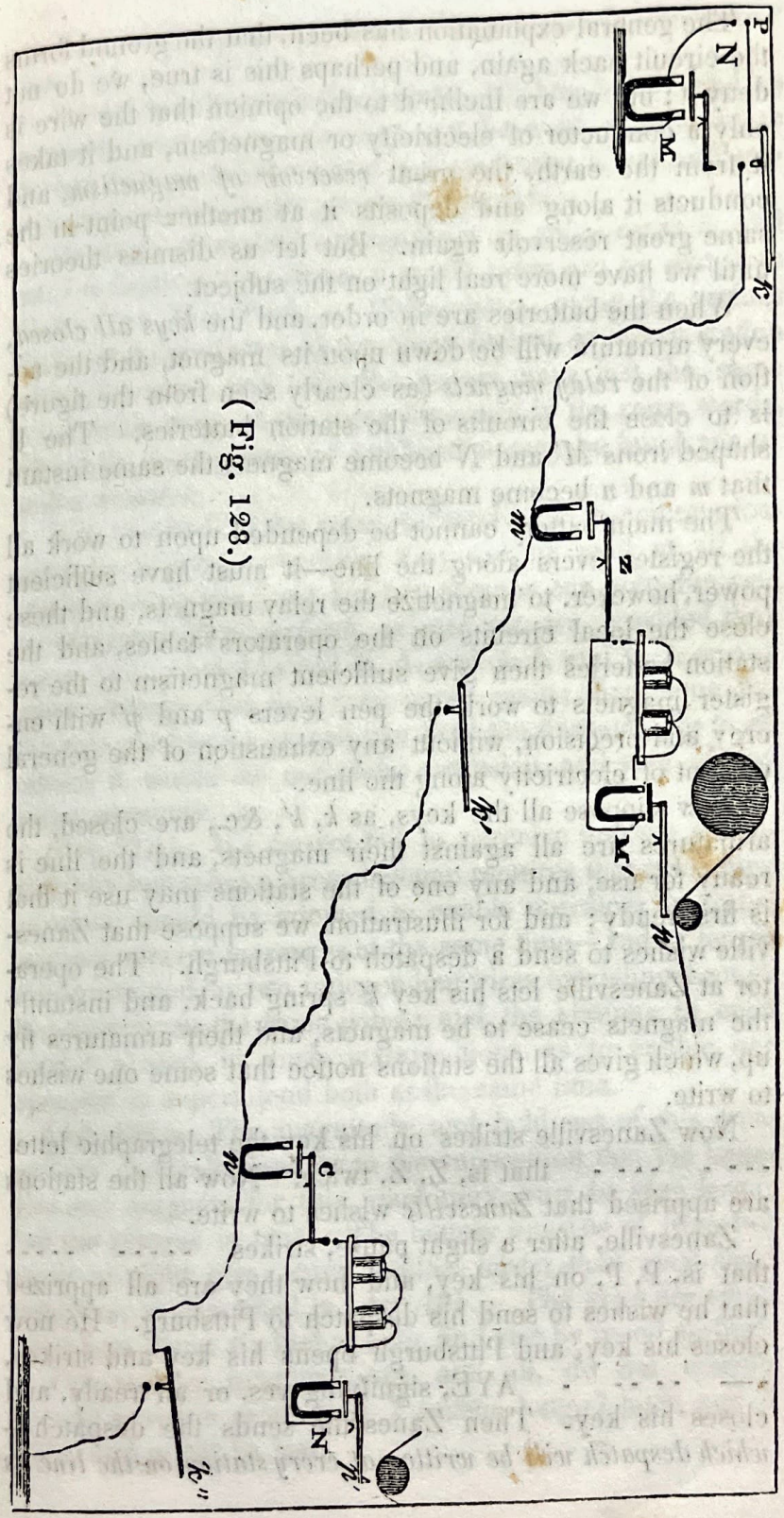
But when the line is *very long*, and there are many intermediate stations, the machinery becomes more complicated, and we must have *relay magnets* and *station batteries*.

On a very long line one battery, even a large one, has not sufficient power to serve all the stations, and the difficulty is overcome as we are now about to explain.

Suppose we take a long line, as from Pittsburgh to Cincinnati, and note one intermediate station, say Zanesville. Let Fig. 128 represent the line, P the station at Pittsburg, the two points representing the two poles of the main battery at that end of the line; Z represents the station at Zanesville, and C that at Cincinnati. Let k, k' and k'' represent the keys at the three stations.

The two magnets m and n, at the two stations Z and C, represented on the line of the main wire, are called *relay magnets*. The magnets M, M' and N are called the *register magnets*. The main battery is at P, not represented The two batteries seen at Z and C, are very appropriately called station batteries, and there may be any number of such stations along a line.

In Art. 173, we represented a complete circuit of wire, but here we have only one wire passing from the ground round the magnet M to one pole of the main battery, and a wire from the other pole to the extreme end of the line, and there terminates in the ground.



(Fig. 128.)

The general explanation has been, that the ground forms the circuit back again, and perhaps this is true, we do not deny it; but we are inclined to the opinion that the wire is only a conductor of electricity or magnetism, and it takes it from the earth, the great *reservoir of magnetism*, and conducts it along and deposits it at another point in the same great reservoir again. But let us dismiss theories until we have more real light on the subject.

When the batteries are in order, and the *keys all closed*, every armature will be down upon its magnet, and the action of the *relay magnets* (as clearly seen from the figure) is to close the circuits of the station batteries. The U shaped irons M' and N become magnets the same instant that m and n become magnets.

The main battery cannot be depended upon to work all the register levers along the line—it must have sufficient power, however, to magnetize the relay magnets, and these close the local circuits on the operators' tables, and the station batteries then give sufficient magnetism to the register magnets to work the pen levers p and p' with energy and precision, without any exhaustion of the general current of electricity along the line.

Now suppose all the keys, as k, k', &c., are closed, the armatures are all against their magnets, and the line is ready for use, and any one of the stations may use it that is first ready; and for illustration, we suppose that Zanesville wishes to send a despatch to Pittsburgh. The operator at Zanesville lets his key k' spring back, and instantly the magnets cease to be magnets, and their armatures fly up, which gives all the stations notice that some one wishes to write.

Now Zanesville strikes on his key the telegraphic letter - - - - - - - - that is, Z, Z, twice. Now all the stations are apprised that *Zanesville* wishes to write.

Zanesville, after a slight pause, strikes - - - - - - - - - - that is, P, P, on his key, and now they are all apprized that he wishes to send his despatch to Pittsburg. He now closes his key, and Pittsburgh opens his key and strikes, - — - - - - - AYE, signifying yes, or all ready, and closes his key. Then Zanesville sends the despatch—*which despatch will be written at every station on the line as*

well as at Pittsburgh, provided the operators let their paper run.

When this despatch has passed, Pittsburgh can send an answer; then some one else can have an opportunity to write; but we believe there are particular hours and special regulations about private despatches.

By this admirable arrangement of *relay magnets* and *station batteries*, the items of public news can be sent from Boston, or New York, or Philadelphia, along the various lines, and be written at the *same instant* at every station along the lines, and thus the papers have just the same telegraphic news at the same time, and in the same words, although their places of publication may be hundreds of miles asunder.

It is objected to, by some, to send private communications by telegraph, because they can be read at all the stations along the line; but two persons can communicate by telegraph in a *perfectly private manner*, provided they agree before hand to call E, A, and A; I, and I, E, or any other change that they may agree upon; then none but the two persons so agreed can read the despatch, for to all others it would be complete confusion, and void of any sense whatever.

(Art. 177.) We cannot fail to perceive that the perfection of telegraphic correspondence requires that some contrivance should be adopted to enable operators to transmit and receive messages at the same time—and at length this is attained, by two independent wires extending through the country on the same poles; and the stations in each circuit placed in such juxtapositions as to enable one operator to superintend both at the same time.

(Art. 178.) The magnitude and boldness of this great scheme naturally lead us to the supposition that the batteries and magnets for this machinery must be very large; but the reverse is true. The battery consists of from two to six or eight glass cups a little larger than good sized tumblers, as described in Art. 161. The keys are small lever bars about six inches long, and rise by recoil springs.

The register, magnet, lever, and all, do not usually occupy a space more than 7 inches long, 7 high, and 5 wide, and might be less.

It must be understood by the reader that no proportionality as to size and space can be preserved in our figures; (Fig. 127) and (Fig. 128), they must not be understood as *maps*, for no maps can be made among things so disproportionate in length and size, as the apparatus at a station and the length of a line. In Fig. 128, the two magnets m and M', the battery, and key k' are not only in the same room, but on the *same table*. The same remarks apply to other stations.

It was at first supposed that the telegraph would only serve to convey a few simple signals, or a communication of a few lines at most; but the most elaborate document can be sent hundreds of miles, and letter after letter will appear on the telegraphic paper as fast as a penman can write them out.

The President's Message, of December, 1847, was telegraphed from Washington to Cincinnati, in about 23 hours, or as fast as clerks and compositors could arrange and set the type at the latter place.

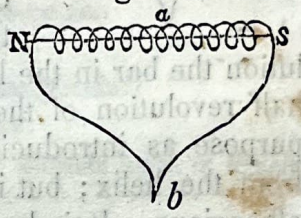
The greatest obscurity, and of course the greatest perplexity, in deciphering a telegraphic despatch, is the want of common punctuation marks and capitals.

"The large offices, (says Mr. Johnson) are necessarily so constructed that the apparatus is either concealed from public view, or so far removed as to secure the operator from interruption. A clerk receives the despatches, notes the number of words, receives the amount of the charge, and makes a memorandum to that effect in the margin. It is then passed to the operator, who transmits it to its destination, and notes in the margin the minute and hour of its being sent. It is then endorsed and filed with the other despatches of that day, ready for convenient reference, if it should be required at any future time. When a despatch is transmitted from another station, the operator writes it out or dictates to a clerk. This is again copied into a letter form, duly sealed, superscribed and sent to its address by messengers who are kept in attendance for that purpose, or by mail, if the distance be too great for the former mode. It is a prime object to bring despatches to their address with the least possible delay, and all the appliances for that end are carefully called into service."

CHAP. VIII.—GALVANIC CURRENTS INDUCED BY THE MOTION OF A MAGNET WITHIN A HELIX—INDUCED ALSO BY THE REVOLUTION OF A MAGNET—MAGNETO ELECTRIC MACHINES—THERMO ELECTRICAL CURRENTS.

(Art. 179.) If it is electric currents passing around iron or steel that causes them to become magnets, we should at once infer that a magnet, either a natural or artificial one, would give an electrical current to a conducting wire, and for some time efforts were made in vain to verify this hypothesis by experiment. At length Professor Faraday succeeded.

Fig. 129.



Let there be a helix of copper wire, (Fig. 129,) the strands of which are kept from touching, and the two ends brought together at *b*. If a magnet *N S* be now introduced into the helix *no electric current will run through the wire*, contrary to theory and expectation, and therefore it was supposed that the theory had failed.

But the theory was too plausible to be readily abandoned, and after close examination it was manifest that an electrical current did flow *while the magnet was passed in;* but as soon as it came to rest, the current ceased. On withdrawing the magnet the current was again induced, but in an opposite direction.

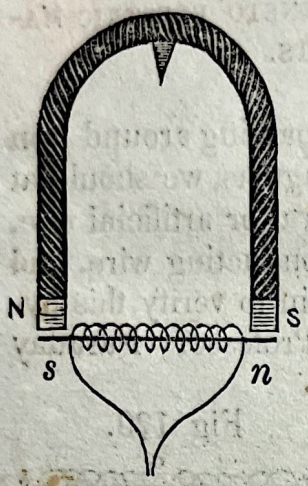
Thus it was discovered that if a natural magnet be rapidly introduced and withdrawn from within the helix, opposite currents of electricity will be induced on the wire, and the change of the current has the tendency to produce shocks.

If we open the wires at *b*, a bright spark is seen every time the current changes, and if the ends of the wire are dipped in water, particles of water are decomposed.

But to introduce and withdraw a magnet from a helix with rapidity would be a very difficult and troublesome operation; but the same result can be effected by placing a soft iron bar in the helix and magnetizing it by induction from a magnet without.

Let a bar of soft iron run through the helix, as repre-

Fig. 130.

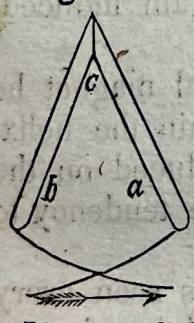


sented in Fig. 130, and let the poles of a horse shoe magnet approach the ends of the bar as represented in the figure. The north pole of the magnet *N* will induce south polarity in the iron bar *s*, and the south pole of the magnet *S* will induce north polarity in the bar at *n*. Now conceive the magnet to revolve on its central point *C*, so as to change the position of its poles in relation to the bar, then the inductive influence of the magnet will change the polarity of the bar, and if the magnet is kept in a state of revolution the bar in the helix will change the polarity at every half revolution of the magnet, and this answers the same purpose as introducing and withdrawing a real magnet from the helix; but it is far more expedient, and twice as efficacious. It induces strong momentary and contrary electrical currents in the wire of the helix, and these rapid and instant changes of current produce electrical shocks.

All instruments constructed to bring this principle into action are called *magneto electric machines.*

(Art. 180.) If a bar of antimony *a* be soldered to another of bismuth *b*, as represented in Fig. 131, and wires connected with their other ends so as to be connected together or attached to any other instrument. Now if these wires be connected with a helix which passes round a magnetic needle, and heat applied at the junction *C*, the needle will be deflected from the meridian and so deflected as to show that the current sets from the bismuth to the antimony.

Fig. 131.



If we cool the junction the needle will be deflected the other way, showing that the current sets in an opposite direction, or from the antimony to the bismuth. This experiment shows that *electricity or galvanism is excited by changes in temperature.* Other metals will do besides antimony and bismuth—but these show the phenomena more sensibly than others. The properties of the metals seems to be a difference in their conducting powers of heat; but a Mr. Canning has demonstrated that one metal will answer the purpose of exciting electricity, as explained in (Art. 174.)

QUESTIONS.

SECTION 1.

CHAPTER I.

What does the term Philosophy imply?

What is a body? What are the essential properties of bodies? What are the peculiar properties of bodies?

Explain extension, divisibility, and other properties.

How many kinds of attraction are there?

Explain *cohesion*. Why are drops of water globular?

Explain the principle of manufacturing shot.

What is meant by capillary attraction? Explain some of the effects of capillary attraction.

When, and by whom was the theory of universal gravity discovered (page 14)? Give the words of the theory.

By what law does gravity vary in its force above the surface of the earth?

What is the *unit for distance*, when we speak of universal gravity (page 16)?

Where is the attraction of the earth greatest? What is the force of the earth's attraction at its centre? Is the force of attraction more or less at the bottom of a well than on the surface of the ground?

Are two plumb lines parallel? Do walls and buildings become wider at the top when built by the guide of the plumb? Should the deviation be taken into consideration? Does a plumb in all situations tend to the centre of the earth?

CHAPTER II.

What is meant by motion? What are the three elements of motion? How are these elements combined?

Explain *retarded* and *accelerated* motion.

What is meant by inertia? Are all bodies inert? What is the effect of inertia on stationary bodies? On moving bodies?

Can a body in motion change the direction of its motion? On what principle is the tendency in a right line?

What is momentum? How do you find the relative momenta of two or more bodies in motion (page 24)? Is motion sensible to our nerves? What is the effect of interrupting motion?

What do we take for the measure of the force of gravity (page 26)?

When a body falls from a state of rest, by what law does its velocity increase? Can you enforce this law, or make it apparent by a course of reasoning? What will be the two main principles used in your course of reasoning?

By what law (in proportion to time) do the distances of falling bodies increase? How far does a body fall during the first second of time? Is this drawn from reason or experiment?

By what law do bodies ascend (page 29)?

When no resistance is made to falling bodies, will all kinds and all masses fall the same distance in the same time? Give a logical explanation of this (page 31). Explain *Atwood's machine.* What is the object of the machine?

Do bodies attract each other equally or proportionally (see page 34)?

CHAPTER III.

When a body moves in a resisting medium, what is the proportion between the velocity and the resistance? Is there a limit to the speed of a ship or a boat? Bodies falling through the atmosphere, do they ever come to a uniform velocity? Do all bodies arrive at the same uniform velocity, or do different bodies attain a different uniform velocity (36)?

Are cannon balls in their flight very much or very little resisted by the atmosphere?

What is said of action and re-action? Cite some examples of the effect of action and re-action. What anecdote was given by Dr. Arnott to illustrate this principle?

What is meant by compound motion?

In what direction will a body move, impelled by two forces? Three or more? Explain on the board.

What is meant by a parallelogram of forces? When we speak of a parallelogram of forces, how many forces are under consideration? When more than two are under consideration, what may their combination be called?

Show the resultant of a *polygon* of forces. Show how you can decompose a force into several other forces.

What is meant by reflected motion?

Explain what is meant by the angles of incident and reflection, and show the relation between them. Show that any pressure against a plane must be to effect a *perpendicular pressure* (44).

Can a ship sail within a right angle to the wind? Show then how a ship can be made to work against the wind.

What is meant by curvilinear motion? What two forces will produce curvilinear motion? Show the points on the blackboard through which the particles of water must pass, in spouting out of the side of a vessel. Show the flight of cannon balls through the air.

What is the relative force of gravity at the surface of the earth, and at the distance of the moon (48)?

What is meant by circular motion? Is circular motion a natural or a construant motion? What is meant by a natural motion?

What is meant by centrifugal force? What effect does centrifugal force have on the power of gravity? What effect has it apparently had on the shape of the earth?

Are bodies heavier at the poles than at the equator, and in what proportion?

CHAPTER IV.

What is meant by centre of gravity?

On what does the stability of a body depend? What must be the shape of a body to be moved with the greatest facility? What figure can be turned over with the greatest ease, a square body or a triangular one of the same base and altitude? Why do trees and plants have a tendency to grow in a perpendicular direction? How do you find the common centre of gravity between two bodies? (Art. 21). How do you find the centre of gravity of a triangle? Explain how you may find the common centre of gravity of a system of bodies, as explained in Art. 22.

CHAPTER V.

If a body runs down an inclined plane, (without friction) in what proportion is the time of descent to the time of falling freely from the same height? What laws govern the fall of bodies down inclined planes?—What will be the velocity of a body at any definite point on a plane (Art. 24)? What is said of the time down any chord of a circle?

What is a pendulum? Does the weight of a pendulum change the time of its vibration? Explain why it should not (page 60). What is the length of a pendulum which vibrates seconds on the level of the sea? If the force of gravity were greater, would a pendulum vibrate quicker?

Is the distance a body will fall in the first second of time, decided by observations on the vibration of pendulums, or more directly on the actual fall of bodies? Can the altitude of mountains be determined by the vibration of a pendulum?

What relation exists between the times of vibrations of the same pendulum at different localities, and the distances of those localities from the

centre of the earth (page 61)? How far up a hill must you go, that a second pendulum shall lose *one second* per day (62)?

What is meant by a compensating pendulum?

Explain the gridiron pendulum?

Why is a pendulum a good standard for linear measure?

SECTION II.

CHAPTER I.

How many simple mechanical powers are there?

What is a lever? How many kinds of levers are there? Describe them.

On what principle do you explain the wheel and axle? Where is the long arm? Where the short arm? Where is the fulcrum?

Describe the double axle. In what consists its efficacy?

What is a compound lever?

What is the relation between the weight and power in a simple lever when they balance on a fulcrum? What is the general relation between the weight and power when they balance in all machines? What is the same relation in a compound lever? On what principle do you describe the relation between the weight and power in a series of wheels?

On what principle do you explain steelyards? Must the bar be of any particular length? Or the poise of any particular weight? Or the hooks of any particular distance asunder? Explain how you may mark off a pair of steelyards. Describe the patent steelyards with its three-fold poise. Explain how large bodies may be weighed with very small steelyards.—Describe the larger weighing machines.

What is meant by a spring balance?

What instrument measures the varying of bodies as they ascend a mountain, or change from the equator towards the poles?

What are the particulars to be attended to in making a delicate scale-beam? How do you detect false balances? How do you find the true weight of any body weighed in a false balance?

What is a capstan? On what principle do you explain its power?—Where and for what purposes is the capstan used?

CHAPTER II.

What power is gained by a rope running over a single pulley?

What is a multiplied cord?

In any system of pulleys how do you find the power from the weight, or the weight from the power?

What is the advantage of White's pulley?

Why should the principle of oblique action give power?

[It ought to have been stated in the text that this principle is applied in sculling a boat.]

What is the efficiency of an inclined plane in raising or supporting weight,—or how do you find the power of the plane? When the power acts parallel to the base of the plane, how do you find the relation between the power and weight?

Describe the slide of *Alpnach*.

What is the power of the wedge, and how is it estimated? What instruments act on the principle of the wedge? What comparison is there between the inclined plane and the screw? How then do you find the advantage gained by the threads of a screw? When a lever is applied to a screw, how do you find the pressure force exerted?

What is the construction of Hunter's screw? What is the advantage of such a screw? How does it compare with the double axle described in Art. 31?

What is a perpetual screw? Are perpetual screws used in mathematical instruments, and for what purpose?

What is meant by friction? Is friction always a detriment to the action of machinery? In what cases is it advantageous? Is friction increased or decreased by the bodies being a longer or a shorter time in contact?—Do carriages experience more or less friction by moving over the same distance with a slow or a rapid motion?

Can you combine the mechanical powers?

Give an example of moving a building, what powers you will use, &c.

Is any real power gained by machinery? What then is the advantage of machinery? What are the acting or moving forces to machinery?—Do forces act continuously, or by impulses? Can you regulate forces to act in either way at pleasure? What force causes a watch to run? What regulates that force? What is the office of a fly-wheel?

SECTION III.

CHAPTER I.

What is the import of the term hydrostatics?

What is meant by a fluid? How many classes of fluids are there?—Do fluids press equally in all directions? How do you make this appear by reasoning? Is the surface of a liquid in an open vessel always horizontal? What use is made of this principle? Were the Romans probably

ignorant of this principle? What is a water level? What is a spirit level? What are the uses of these instruments?

What is the pressure of water on the bottom of a vessel? Does the pressure depend on the quantity of water? On what does it depend?

What is the hydrostatic paradox?

Describe the hydrostatic bellows.

Describe the hydrostatic press. How do you compute the power of the press?

CHAPTER II.

What is specific gravity? What is the standard for gravity to which solids may be compared? What is the standard for gases? How do you find the specific gravity of a body that will sink in water? How do you find the specific gravity of bodies that float on water? Give the rule. How do you find the specific gravity of liquids?

What is a specific gravity bottle? Why should it have a long and narrow neck?

What is the use of specific gravity? Can you find the contents of irregular bodies by their weight and specific gravity? Describe the process. Can you detect mixture in a liquid by means of specific gravity? How did Archimedes discover that a jeweller purloined gold from Hiero, when he returned the same weight of metal?

CHAPTER III.

What is meant by the term hydraulics?

With what velocity does water issue out of the side or bottom of a vessel? How is this shown by experiment? At what point must an orifice be made in the side of a vessel that it may project to the greatest distance on the horizontal plane from the bottom? From what two points will the horizontal ranges be equal? Will a straight pipe convey more water than a curved one of the same diameter? Does the length of the pipe have any influence on the quantity of water discharged, other circumstances being equal? What should be the comparative length and diameter of pipe to discharge the greatest quantity of water possible?

On what principle do you explain the flow of rivers? Does the flow of rivers correspond with the theory of bodies falling down inclined planes? How do you find the actual flow of a river by experiment (page 114)?

Describe the chain pump.

Describe Archimedes' screw. Does water run up in this screw? How then is it raised up? Does the water run down in this screw? Is any power lost by this mode of lifting water?

How many kinds of water wheels are there? Describe them.

Describe Barker's centrifugal mill. On what principle does it act?—Why is it called *centrifugal* mill? Is it used in cold countries?

CHAPTER IV.

What is meant by pneumatics? Do we live in a fluid? Could we live without this fluid? Are we sensible of the pressure of the air? Why? How shall we bring the truth to our senses? What is the pressure of air on a square inch? How is this discovered,—how do we know that it is more than ten pounds on a square inch? Is the pressure always the same? How do we know this? Is the pressure as great on a mountain as in the valley below? Does this fact correspond with theory?—What instruments must we have to make experiments on the elasticity and pressure of the air?

Is the air pump the same in principle as the common pump? What is a valve? How many pump barrels has an air pump? Are the two essential, or will one suffice? How many valves are there in each barrel? Which way do they open, up or down?

Can we pump all the air out of a vessel? Why not? Explain how the air passes from the receiver out of the pump barrels without returning. By what kind of an experiment can we show the pressure of the air?—Explain the experiment of the Magdeburg hemispheres. Who invented the air pump? How do you show the elasticity of the air by means of the pump. Describe *le jet d'eau.* Is there any method of producing a perfect void (Art. 63)?

What is the object of the barometer? Describe the instrument. Describe the wheel barometer. Is it essential that the barometer tube should be of the same diameter in every part? Does it make any difference whether the tube and quantity of mercury is larger or smaller? How many feet of the lower strata of the atmosphere corresponds to one-tenth of an inch of mercury? How can we find the real weight of a cubic foot of air by this observation? How can you compute the entire weight of the whole atmosphere?

By what law does the density of the air decrease as we ascend upwards? What effects of atmospheric pressure are experienced by travelers on a mountain? How does the barometer indicate changes of weather?—What is the use of the barometer at sea? What incident is related by Dr. Arnot?

Describe the common pump. When does the piston valve open?—When does the lower valve open? What sustains the water in the pump barrel? How far can you draw water by means of the common pump? Do pumps which lift the water from unequal depths work with the

same ease, other circumstances being equal? Why does a long pump require more force? How can we raise water more than thirty-three feet by a common pump?

Describe a *forcing pump*.

What drives the water from the air vessel? How is the air compressed in the air vessel?

What is the difference between a *forcing pump* and a water, or as it is commonly called, a fire engine?

Describe Hiero's fountain. Is there any practical utility in this fountain, or is it merely a philosophical toy?

What is a syphon? What are its uses? On what principle does it act? How high can liquids be made to ascend in a syphon? Must the point of discharging always be lower than the fountain, for the syphon to operate?

Define wind. What is the principal cause of wind?

What causes a current of air up a chimney or stove pipe?

Define land and sea breezes, and state their causes? In what countries or climates do they occur?

What are trade winds? Where do they occur? What occasions them? Are these winds strong at the equator? What is their direction at the equator?

What are *monsoons?* Where do they occur?

Describe the prevailing winds in the Indian ocean.

What gave rise to the idea of poisonous winds in Africa and Arabia?

How do you explain *dew?* Rain? Hail?

Draw the steam engine on the board, and describe the action of the steam to keep machinery in motion.

What has Dr. Arnot said of the steam engine?

CHAPTER V.

What is meant by acoustics?

What is the primary cause of sound? How are sounds conveyed to the ear?

How is it proved that the atmosphere is the medium by which sounds are commonly conveyed?

Are sounds as great on a mountain as below?

Are sounds heard farther at night than in the day time? What reasons have been assigned for this fact?

How far has the human voice been heard?

Are sounds heard to a greater distance over water than over land?

Can a cannon be heard at a greater distance in one direction than in

another? and if so, in what direction can it be heard at the greatest distance? In what direction should a bell be swung?

Is air the only medium by which sounds can be conveyed?

Are other and more solid bodies more rapid and better conductors of sounds than air, or otherwise? Describe the experiments by which we learn these facts.

Is sound instantaneous or progressive? How fast does it move through the air?

Do all sounds, great and small, go with the same rapidity? Does sound move with any greater rapidity when first created, than afterwards?

Can we apply sound to the measure of distance?

How much more rapidly does iron convey sounds than air (page 146)?

Can sounds be reflected?

What law governs the angles of incident and reflection?

What is an echo?

How do we account for the rolling sound of thunder?

Are echoes ever heard from cannon discharged on the sea, or in an open plane country?

What would be the effect of a person speaking in the centre of a circular room?

What is a whispering gallery? What is the shape of the room?

What two points are most favorable to place the speaker and hearer and have them a considerable distance asunder?

What should be the shape of large audience rooms?

How do we judge of the locality of sounds?

What effect has our previous impressions, hopes or fears, on the duration of sounds? State some cases in point.

Why do wicked or timid persons hear strange sounds?

What peculiar faculties must a *ventriloquist* possess? How does he manage to control the imagination of his auditors?

In what essential do musical sounds differ from other sounds?

What kind of tones do large instruments or large strings produce?

What kind do small instruments and small strings produce?

What are speaking trumpets? What is their use?

What are sounding pipes? Where are they used?

SECTION IV.

CHAPTER I.

Define optics. Do we understand the true nature of light?

What two theories are there concerning light?

What are luminous bodies?

What are opaque bodies?

What are translucent bodies?

What is meant by a ray of light? By a beam of light? What is a pencil of light?

What are convergent and divergent rays?

What is meant by a radiant point? What by a focus?

Do rays of light proceed in right lines? Will this simple fact ever give inverted images (Fig. 80)?

Is light instantaneous or progressive? What is its velocity per second? How is this discovered?

By what law does light *decrease* in intensity, as the distance *increases*?

CHAPTER II.

What is meant by reflection of light?

What is meant by a reflector? How many kinds of reflectors are there?

What is the general distinction between a mirror and a speculum? Does light follow the same law of reflection as material bodies do when they strike a plane? What is that law?

How far is an image behind a mirror? Is this in consequence of the law of reflection just cited? Can you make this appear by a drawing on the black board?

When an object is placed between two parallel mirrors, how many images are formed, and in what order?

What name is given to this appearance?

When three small mirrors are placed in a triangular position in a tube, what is formed?

What objects are used, and where are they placed in the kaleidoscope?

How do you try the goodness of a mirror?

What is said of large, perfect mirrors?

On changing the position of a mirror any number of degrees, how many degrees will an image change? What instruments are constructed on this principle?

On what principle do you explain concave mirrors?

Define the axis of a concave mirror.

What is the position of parallel rays? Where is the focus for parallel rays? Where for diverging rays? Where for converging rays?

Explain how images can be formed in the air before concave mirrors.

Are such images direct, or inverted?

What is meant by *conjugate foci*?

What phenomena may be observed by a person looking into a concave mirror from different positions?

What is said of the strength of imagination, and the power of former impressions, in making these observations?

What is said of the exhibitions of showmen?

Can concave mirrors be used for burning?

How is it supposed that Archimedes set the Roman fleet on fire, in the harbor of Syracuse?

Explain *convex* mirrors.

Define the axis of a convex mirror.

Has a convex mirror any focus?

What is meant by a virtual focus?

When images are seen in a convex mirror, are they larger or smaller than their objects?

CHAPTER III.

What is meant by refraction of light? Why do oars and long poles appear broken just at the water's edge?

What experiment is made by a coin in a cup?

What is meant by the *constant* of refraction?

Do all transparent media have the same *constant* or index of refraction?

Has the atmosphere a constant of refraction?

What effect does atmospherical refraction have on the height of the heavenly bodies?

What is the shape of a multiplying glass?

Do we always determine the locality of an object to be in the direction of the last portions of the rays of light that meet the eye?

Does the refractive power of the atmosphere differ, at different times and temperatures?

What experiment was made by Dr. Wollaston?

What did such experiments explain?

What is meant by *mirage, looming, and unusual refraction?*

What was observed by Dr. Vance, at Ramsgate?

What was observed by Capt. Scoresby, in the Greenland seas?

What has been observed at the city of Reggio?

What was observed by Dr. Buchan, in England, in 1804?

What was observed by the French army in Egypt?

How is this last phenomenon explained?

CHAPTER IV.

What is meant by the term chromatics?

Do we know much about the real nature of light?

Has light any connection with *heat* and *electricity?*

Is light a simple substance? By what evidence do we decide that it is not?

What is meant by a prism?

What is a spectrum?

How many colors are in the spectrum? What are these, and in what order do they stand?

Are these colors separated by distinct lines of demarcation?

What experiment is made with seven colored powders, and what conclusion is drawn from it?

When a single color is made to pass through a second prism, is it farther decomposed?

What conclusion is drawn from this fact?

How many real primary colors do there appear to be?

What are those colors?

Do all agree in this, and why not?

What is said of the heating power of the spectrum? What of the illuminating power?

What is found in the spectrum when closely examined by a microscope?

What is said of the chemical effects of the solar light?

What experiments were made on the solar spectrum by Mrs. Somerville?

Do prisms of different kinds of glass give spectrums of the same length?

What is meant by *dispersive* power? What substance has the greatest *dispersive* power?

On what principle do you explain the colors of the *rainbow?*

Is each rain drop a prism? If so, why does not each drop give all the colors?

Do we ever see more than one rainbow at a time?

Can we make an artificial *rainbow*, and how?

Which of the two bows is called the primary bow?

What is the order of its colors?

Why should the upper edge of the primary bow be *red?*

Is the order of the colors the same in both *bows?*

Can rainbows be formed when the sun is very high?

What is the diameter of the primary bow?

What is the width of the space between the bows?

How do you account for the different colors of the clouds, and the varied color of the sky?

What is said of the natural color of bodies?

CHAPTER V.

What is the foundation principle of all optical instruments?

What is a lens?

Show the action of a lens on the apparent size of objects?

What is a simple microscope?

How many kinds of lenses are there?

What is the action of a concave convex lens?

What is the action of a *meniscus?*

Define the axis of a lens.

What are parallel rays? What are convergent and divergent rays?

What is meant by a focus to a lens?

Where is the focus for a plano convex lens for parallel rays?

What is the focal distance to a *meniscus?*

Give the rule.

Will convex lenses produce images in the air, by refraction?

Why should they more than a plane glass?

Where, or at what distance from the lens are images called?

Has every point on one side of a lens a corresponding focal point on the other side?

Can the images be seen without some medium to arrest them?

Why are these images called *ærial images?*

At what distance is the human eye most acute?

What effect has distance on the apparent magnitude of an object?

When an object comes nearer, how do you find its increase of apparent magnitude? Give the rule (page 188).

Are the images formed by convex lenses erect or inverted?

What is the magnifying power of a convex lens when the eye views the image at the distance of six inches? Give the rule.

When the object is at a very great distance from the lens, what then is the rule?

Can there be a single lens telescope?

What other glass is necessary to make the refracting astronomical telescope?

What chemical effects has light on color? What effect has it on dead vegetables?

What is the foundation of the Daguerreotype art?

CHAPTER VI.

Will a spherical lens refract all the rays of light to one point?

Parallel rays that are most remote from the axis, will they form a focus nearest or farthest from the lens?

Define longitudinal spherical aberration, and latitudinal spherical aberration. What is the shape of a convex lens having the least spherical aberration? What is the amount of this aberration in proportion to the thickness of the lens?

Define chromatic aberration? What colored rays will have their focus nearest the lens? Are the two kinds of aberration confounded together? How can you show chromatic aberration apart from spherical aberration? What is meant by the circle of least aberration?

What difficulties are in the way of making a perfect refracting telescope? By what means can spherical aberration be corrected (Art. 116)? Why did Newton give up the improvement of the refracting telescope as hopeless? When spherical aberration was corrected by an elliptical shape of the lens, what other difficulty was increased? Can the two aberrations be removed by the same process, or nearly so?

What two kinds of glass are used to form an *achromatic* lens? What is meant by the *dispersive* power of glass?

Describe the action of the compound lens, as explained in (Fig. 102) to form a colorless image. What expedient can be employed to correct aberration, and use a small piece of flint glass (Art. 118)?

How many glasses has an achromatic eye-piece? Explain how these can destroy color. Does the astronomical telescope show objects erect or inverted? Are such telescopes objectionable for terrestrial objects, and why?

What is the construction of an erecting eye-piece? What must be the construction of a lens to be a telescope? What to be a microscope? How do you find the magnifying power of a telescope consisting of two lenses?

What is a reflecting telescope? Describe Newton's reflective telescope. How does Gregory's differ from Newton's. Which is best, the reflective, or the refractive, and why?

CHAPTER VII

What is the most perfect optical instrument? What, and where is the first refractive medium in the eye? What is the *iris*, and what its office?

What is the shape of the *crystalline humor*, and has it spherical aberration? Where is the vitrious humor? Where is the *retina?* Where is the sense of vision?

Are images formed on the retina, erect or inverted? If inverted, why do we not conceive objects to be upside down? How do we know, in fact, that images are upside down on the retina? What seems to be the office of the black pigment behind the retina? When the eye is too

spherical, what is the consequence and what is the remedy? When too flat, what is the consequence and what the remedy? What influence has health on vision? What intoxication?

CHAPTER VIII.

What is the construction of the compound microscope? How do you find its magnifying power?

What analogy is there between telescopes and microscopes, and the magic lantern and solar microscope? Is there any difference in principle between the magic lantern and the solar microscope? What then is the distinction between them?

In the magic lantern do you see the object, or its image? What kind of objects are used, large or small ones? Where are they placed?—Where are their images thrown? Are the images illuminated surfaces or shadows?

In the solar microscope what is the office of the mirror outside of the window? Can it always be so turned as to reflect the sun's rays through the lens?

What is a perspective glass? How is the mirror placed to receive horizontal objects?

What are burning glasses? What is said of the intensity of the heat which concentrates?

SECTION V.

CHAPTER I.

What is the origin of the term electricity? What are electrics and non-electrics? Name some of the most noted electrics. Do we really know anything of the essential nature of electricity?

How is electricity produced? Is it produced by the friction of all bodies? Do all bodies conduct electricity? Define conductors, non-conductors, &c. How does electricity show itself? Does electricity from all bodies show the same effects at the same time?

Will glass and wax attract any light substance at the same time?

What theories have been deduced from this fact, and by whom?

What is Franklin's theory? What is DuFay's? Does glass always acquire the positive electricity? Is the atmosphere a conductor of electricity? If it were, should we know even of the existence of electricity?

CHAPTER II.

What is the most simple electrical machine? What two forces are commonly given to machines?

Describe the plate machine. Should the machine be insulated? What kind of amalgam should be put on the rubber? What difficulties do young operatives experience in making experiments?

What is a prime conductor? Should a prime conductor be insulated, and if so, why? What would be the effect if it were not insulated?—How do you insulate a prime conductor?

What is an insulating stool? Can an insulating stool be made of any other substance than glass? How can a person become part of a prime conductor? Does a person standing on the glass stool and receiving electricity from the prime conductor, feel the fluid? What effect does it have on his hair?

When you touch a person so situated, what is the effect? When you take a spark from a person on the insulating stool, who feels it most sensibly, the person, or the one who touches him?

How can you inflame alcohol and other combustibles by electricity?—What is an electrometer? Describe the gold leaf electrometer? Why should it be covered by a glass case? Why should the metal be gold leaf? would not silver leaf do as well, and if not, why? What is said of the sensitiveness of this electrometer?

Describe the quadrant electrometer? Which is most sensitive, this, or the gold leaf electrometer? Where do you place the quadrant electrometer, in what part of the electrical machine?

What experiments are made to show the conducting power of bodies? How do you show the *pantomime dance*, and what principle does it illustrate?

Describe the fly-wheel, and give your reason why it should have motion when brought near the prime conductor, while the machine is in action.

Describe the operation of the electrical bells. What principle of action causes them to ring? Is the center bell suspended by a conductor or by a non-conductor? Why should the center bell have a chain attached to it leading to the floor or ground?

What appearance will electricity present on broken, insulated conductors, like broken pieces of tin foil or glass?

What is the appearance of the electric fluid in a partial vacuum?

What inference is drawn from this?

CHAPTER III.

What is meant by electrical induction? By what experiments do you show electrical induction?

Describe the Leyden jar. From what does it take its name? Give us something of its history, and explain how its principle was discovered?

How do you charge a jar? What principle is illustrated in charging a jar? What was said of the shock received from the jar by its first discoverers? Were they sincere in their exaggerated accounts, and if so, what caused the exaggeration?

How do you discharge a jar? Describe a discharger. Why should it have a glass handle? Why should a connection between the two coatings discharge the jar?

Can a person become a discharger, and when is he so? How do you unite several jars, and when so united what are they called?

When several jars are united, do they differ in principle from one jar How do you charge a battery? How do you discharge a battery?

How do you charge a jar negatively? Will two jars of the same surface and same coatings, receive and give the same amount of shock, and if not, why?

What objection is made to very thin jars?

How long will a jar or battery remain charged? Why should the charge escape at all? Can you silently discharge a jar, how, and on what principle?

Is the electricity on the coatings of the jar or on the glass? By what experiments is this proved?

What is the real use of the coatings? Should children or reckless persons be allowed to play with a battery?

CHAPTER IV.

How, and by whom was it proved that the electricity of machines and the lightning in the atmosphere are identical?

How were the experiments conducted? Were these experiments dangerous? What fatal effects happened? Are such experiments now made?

What is said of the electricity of steam?

What is said concerning the origin of electricity in the atmosphere?

What are lightning rods?

What is the object of putting up a lightning rod? Are trees lightning rods?

Are they as good as metallic rods? Do rods or trees draw the electricity from a distance?

Should the doors and windows of a house be closed when a thunder storm is rising, and why?

What story of a building is most safe? What is said of a chimney as to its safety? Can a person absolutely protect himself from electricity, and if so, how? Should a person take shelter under a tree during a thunder storm, if not, why?

Are silk garments any protection?

What is said of the origin of thunder and lightning—does it produce the storm—or is it one of the effects of the storm?

What is said of the fire balls which sometimes appear at the extremities of the yard-arms of vessels?

CHAPTER V.

GALVANIC ELECTRICITY.

What is the origin of the term galvanism? How is galvanism produced?

Describe the cups and metallic plates.

What is a simple galvanic circle? What is a compound galvanic circle? Describe the galvanic pile.

How do you take a galvanic shock?

Describe Dr. Wollaston's battery. What is the difference in effect between a battery of a great number of plates, and one of the same surface in a few large plates?

Can you charge the Leyden jar by a galvanic battery?

What is the difference between *quantity* and tension in electricity?

What are the chemical effects of galvanic electricity? Describe the burning of the metals in the galvanic circuit.

Does the decomposing power of a battery depend on the quantity or tension? Describe the cylindrical battery.

Describe Grove's battery. How long may be the wire that connects the two poles of a battery?

What is meant by electrotype?

Describe the apparatus for taking electrotypes. Why should the inner cup be porous?

In which cup do you put the zinc, and into what liquid? Should the galvanic action be vigorous or weak, and why?

Would you deposite the metal from the salt on the metal, or on a mould, and what would be the difference?

How are moulds taken in Newton's fusible metal?

When wax and plaster moulds are taken, what is spread over the surface, and why?

In the same way can you gild and silver metals?

What must be the difference in respect to the galvanic action? Can any one gild and silver by means of galvanism?

What is said of coppering and copper fastenings on the bottoms of ships?

CHAPTER VI.

What is understood by magnetism? What is a load-stone? What metals can acquire the same power?

What are artificial magnets? What is a magnetic needle, and what is its peculiar property?

What is said of the practical utility of this property?

Does the magnetic needle point due north and south? When was this first noticed, and by whom? What comparison is made between magnetism and electricity?

What is a horse-shoe magnet, and what is the advantage of that shape? Is the strength of magnets in proportion to their size?

How is magnetism communicated?

What is said of the earth? By what facts do you prove the earth to be a magnet?

How do you magnetize iron by induction from the earth? When freely suspended in all positions as by a thread, what direction does the magnetic needle take?

Where is the north magnetic pole?

What is meant by dip? What is meant by variation? How many kinds of variation are known? Where is the line of no variation in the United States?

What is the magnetic equator? Is the magnetic equator a regular line on the earth?

What comparisons are drawn between galvanism and electricity?

CHAPTER VII.

What influence has a galvanic current on the magnetic needle?

Explain what takes place on charging the conducting wire which unites the poles of a battery from above to below, from east to west of the needle. What currents are supposed to circulate on the needle? How did Prof. Faraday prove that currents pass round a magnet?

What is the effect of putting a bar of soft iron in the helix of a galvanic wire in action?

Describe the magic ring and its influence. What use is made of that power shown in the magic ring?

How are powerful temporary magnets formed? Who made the most powerful one about the year 1831?

Can the battery and the magnet be far asunder? What advantage is taken of this point?

Describe as well as you can the principle of the magnetic telegraph?—Is the iron magnetized all the time?

Is it magnetised while the operator opens his key or when he closes it? Is the magnet as strong when the wire runs a great distance from the battery to the magnet?

Can any kind of marks be made by the magnetic pen?

Can an electrical or galvanic current be generated by heat? What kind of electricity is this called?

What is supposed to be magnetised by such electrical currents?

What remarks are made on the supposed influence of electricity on climate?

Why does the author bring in remarks about climate while on the subject of electro-magnetism?

What is said of the magnetism of the conducting wire between the poles of a galvanic battery?

Is it probable that the conducting wire of a magnetic telegraph which extends through a large section of country, is in a state of constant electrical excitement, and if so, from what source is the electricity obtained?

Does a current of electricity really run along the wire?

How was it discovered that one wire extending through the country would serve for the operation of the telegraph?

If one wire only is used, how is the connection made between the two poles of the battery?

What is meant by a *relay magnet*?

What is the difference between a relay magnet and a register magnet?

What is the action of the relay magnet? What is the action of the register magnet?

When the line is in order, are all the keys opened or closed? Are the irons magnetised when the keys are open or closed?

How does an operator give notice that he wishes to write?

Is notice given to all the stations at the same time?

Can a dispatch be sent from one point to all the other stations at the same time?

Do all the papers have the same telegraphic news all along the line, and if so, can two persons communicate by telegraph in a perfectly private manner, and how?

What is said of the size of the batteries and other apparatus at the stations?

Are plates or figures 127 and 128 intended as maps, or only the representation of principles?

Can long letters or public documents be sent by telegraph?

CHAPTER VIII.

If electricity can produce magnetism in iron, inversely, can a natural magnet produce electricity?

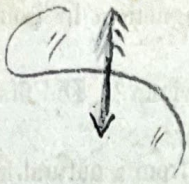
How is this shown, and by whom? Did first experiments succeed, and why?

When electricity is induced from a natural magnet, what name is given to the apparatus?

What does figure 131 represent? What difference is made whether you heat or cool the junction?

To excite electricity by change of temperature, is it particularly essential to have two metals?

The foregoing questions embrace the general substance and spirit of this work, but it is not intended that they should be literally followed. Every teacher should ask his own questions in his own words, and in his own way; and no set questions, however good and to the point, can be rigidly followed, without danger of becoming formal, spiritless and dull. Besides, written questions are drawn up in a consecutive manner, and each question pre-supposes that the preceding one has been answered correctly; but this, in practice, is not always the case, and when a question is answered incorrectly, it often elicits another question from the teacher, given for the purpose of showing the scholar his error, or for the purpose of putting him right. In this way a series of questions may be asked, wholly unpremeditated by the teacher, and not anticipated by the pupil.



Natural Philosophy.